3.0 PLANNING FOR GROUND WATER/FUEL EXTRACTION AND GROUND WATER INJECTION SYSTEM This chapter summarizes procedures and tools for use by the designer of a ground water remediation system. The core of this chapter is a series of checklists that identify data needs for the following phases:

- Remedial Investigation/Feasibility Study
- Design
- Construction
- Startup
- Operation and Maintenance

Each checklist asks the question "Will I need the following information at [phase]," then provides a comprehensive list of possible information and data the designer or others will need in order to proceed to that phase. Like the "trouble-shooting" tables in Chapter 2, this chapter describes the elements of each checklist. This chapter also includes a chart of key system components to assist the designer in the avoidance of many of the common system problems presented in Chapter 2(see Table 3-1 located at the end of Chapter 3).

3.1 Remedial Investigation/Feasibility Study Gathering information during the site investigation phase is critical to proper completion of a project. The remedial investigation and feasibility study should have clear data quality objectives that govern the collection of data discussed in the following sections. All sources of geologic/ hydrogeologic information should be queried prior to beginning this site investigation phase (USEPA 540/G-89/004 (OSWER Directive 9355.3-06),1988; ASTM D5730).

3.1.1 Site Conditions General site conditions, geological and hydrogeologic conditions will be discussed in subsequent sections.

3.1.1.1 Topography Topographic features are used to evaluate accessibility for surface structures, and need for pumps versus gravity flow for transport units. Topography can also be a potential indicator of subsurface geological formations. Topographic data are also used to assess drainage patterns, including run-on and run-off, ponding of water, potential recharge areas and impact to lakes and streams.

3.1.1.2 Adjacent Land Use On-site activities should be assessed for their impact on surrounding receptors and/or facilities whether residential, recreational, agricultural, or industrial. Adjacent land uses can impact activities or results of activities such as hours of operation, air emissions (including dust), nuisance odors, nuisance noise, visual limitations and overall public relations. Assessment of adjacent land use is critical for related issues such as potentially impacted ground water use (See 3.1.1.4 Well Search and 3.1.1.5 Nearby Receptors). Analysis of adjacent land uses and adjacent buildings/structures may also indicate availability of utilities. (See 3.1.1.6 Access to Utilities).

3.1.1.3 <u>Climate</u> Precipitation and annual temperature ranges impact the design, operation, and maintenance of the system as well as site access (see 3.1.1.1 Topography). Protection and control systems are designed specific to the local weather conditions. Examples of impacts are "freezing pipes", precipitation exceeding containment capacity, frost heaving, snow loading to roofs, flooding and erosion around critical system components.

3.1.1.4 <u>Water Well Search</u> A water well search is conducted to determine whether a contaminant plume has possibly impacted or is likely to impact drinking and other types of water wells. The designer must consider whether extraction or injection will have an impact on the use of those wells due to drawdown or hydraulic mounding. A thorough search on other draws from the system should include other remediation projects or large extractions for agricultural industrial use. Water rights to the formation should also be determined at this time.

3.1.1.5 <u>Nearby Receptors</u> Analysis of nearby receptors is used during the RI to determine appropriate remedial criteria and points of compliance. In addition, collected information is used to determine appropriate safety measures and contingency plans for remedial systems. (See 3.1.1.4 Well Search and 3.1.1.2 Adjacent Land Use). A contingency plan should be developed which specifies actions to be taken when controls fail or monitored criteria are exceeded.

3.1.1.6 <u>Access to Utilities (Water, Gas, Electric, Sewer Transportation)</u> Utility access should be considered so that provisions for tie-in to the site can be planned. In addition, the locations of underground and overhead utilities must be determined for the safety of investigators and construction workers. Permitting issues for water and sewer access should also be considered.

3.1.1.7 <u>Site Drainage Conditions</u> Site drainage conditions determine the requirements for run-on and run-off protection (berming, grading, filling, diversion structures, etc.), containment structures for potential spillage, siltation and erosion protection. Impacts of flooding on access and operations must also be considered. Infiltration rates/recharge rates from surface water to ground water can be assessed by analysis of site drainage conditions.

3.1.2 Contamination Sources and Type Characterization The accurate and complete characterization of the type and source of contamination at the subject site is critical to the effective design of any groundwater extraction/injection system.

3.1.2.1 Source of Contamination Information on the source of contamination is used to evaluate the nature of the contaminants, the estimated release volume, potential for continuing contributions, the time of the initial release, and the rate of plume movement. This information also may indicate the potential for LNAPL. It is important to identify all contamination which may affect system operation, not just the primary contaminants of concern.

3.1.2.2 Age of Contamination The age of the contamination is used to estimate the contaminant mass/volume, potential for free-phase, and weathering/ degradation of the release. These data can be indications of the potential for intrinsic remediation (natural attenuation).

3.1.2.3 Distribution of Contamination The distribution of contaminants is used to estimate the types and extent (present and future) of dissolved ground water standard exceedances, and to estimate the volumes and extent (present and future) of LNAPL (if any). Detailed guidance for performing this task is provided in Farr et al., 1990 and Parker et al., 1990.

Information on the type and extent of soil contamination can be used to plan health and safety procedures for on-site workers. Comparison of data from vadose zone soils and saturated zone soils can be used to estimate leachability of compounds and measurement of physical/chemical/biological/toxicological properties. These data are also used in fate and transport models to compare performance of remedial alternatives during the FS and to estimate the need for complementary treatment (such as excavation and disposal, infiltration, etc.); and long-term needs for amendments (nutrients, oxygen or equivalent, surfactant, etc.).

3.1.3 Hydrogeology/Soil Characterization Accurate characterization of site hydrogeology and soil characteristics is an essential step in the process of effective system design. Incomplete information about site hydrology can result in improperly designed systems.

3.1.3.1 Soil Type/Description Information on soil type is used to identify water bearing zones and confining layers and to estimate porosities and permeabilities. Soil type information is also used to evaluate trench slope stability. The most common method for soil classification is the Unified Soil Classification System (USCS), which includes both a field classification procedure (ASTM D2488) and a laboratory classification procedure

(ASTM D2487). These procedures ensure consistency of soil classification and soil characterization.

3.1.3.2 Stratigraphy Stratigraphic data are used to map the horizontal and vertical distribution of water-bearing zones, aquitards and confining layers through correlation between borings and wells. Stratigraphic correlations are used in concert with knowledge of depositional environments (lacustrine, alluvial, saprolitic, glacial, tidal etc.) to determine lateral continuities of transmissive and confining units. The degree of discontinuity and amount of vertical layering influence wells and trench design. For example, flood plain deposits containing thin, discontinuous lenses of silty sand within clays would likely be more amenable to installation of extraction trenches than wells.

Confining layer data are used to evaluate the depth and screen location for wells set into confined aquifers or to avoid breaching of confining layers to protect clean aquifers.

3.1.3.3 Depth to Water/Seasonal and Fluctuations These data are used to determine appropriate well depths, screen lengths, contaminant smear zones and impact of fluctuations on recoverable LNAPL volumes.

Short term (days and weeks) water level fluctuation data are used to define operating procedures. Long term (months and years) water level fluctuation data are used to ensure that upward or downward water level trends are accounted for in screen placement.

3.1.3.4 Total Porosity Porosity is the unitless ratio of void space to total soil volume which is used to estimate the potential water or free-phase holding capacity of the rock or soil. Effective porosity is used to estimate the interconnected holding capacity (void space) of the soil or rock. Total porosity is calculated from bulk dry density (Danielson and Sutherland, 1986) or measured directly (ASTM D4404-84).

3.1.3.5 Specific Yield (Effective Porosity) Specific yield is a measure of the interconnected soil porosity from which water will drain under gravity. Specific yield is used in contaminant transport calculations and in models to estimate cleanup times Hall et al., 1991. Specific yield is also used in calculations to estimate the total amount of recoverable LNAPL (Farr et al., 1990; Kaluarachchi, 1989 & 1990; Parker, 1990. This parameter is rarely measured directly, but is estimated from grain size (Driscoll, 1986; Todd, 1980; and Helweg et al.; 1983) or from comparison of soil moisture measurements and total porosity measurements from above the capillary fringe (but below the root zone). Specific yield is closely related to storage coefficient and storativity which are used to estimate the length of time for steady state conditions to be established after extraction/injection commences (McDonald & Harbaugh, 1988).

3.1.3.6 Grain Size Grain size distribution measurements are used to estimate effective porosity and permeability of the soil and rock. In addition, these measurements are used to design appropriate filter pack gradation and screen slot sizes for recovery wells. Grain size distributions are typically measured using procedures defined in ASTM D422 and ASTM D1140.

3.1.3.7 Bulk Dry Density Bulk dry density is the ratio of dry soil mass to soil volume. Bulk dry density is used to estimate total porosity and is used in contaminant transport calculations. Bulk density is measured using procedures defined in ASTM D4564.

3.1.3.8 Buffering Capacity Information on buffering capacity is used to assess the soil/ground water pH stability and resistance to applications of more basic or acidic amendments or to processes (e.g. bioremediation) which generate acidity or alkalinity. Buffering capacity is used to assess the potential to address scaling, water hardness and related issues by pH control or modification. It is an indicator of pH-dependent incompatibility reactions during applications of amendments to enhance ground water extraction, injection, or treatment in-situ or ex-situ. Reference Hem (1983) and Drever (1982) provide information on measurement and interpretation of buffering capacity.

3.1.3.9 Hydraulic Conductivity (Permeability Coefficient) Hydraulic conductivity is used to estimate contaminant migration rates and the sustainable extraction/injection rates of wells. Hydraulic conductivity can be measured using laboratory permeability (ASTM D2434), aquifer slug tests (Bouwer and Rice, 1976), and aquifer pumping tests (Driscoll, 1986; Kruseman, 1990; Walton, 1988). In general, pumping tests provide the most reliable data for design of extraction systems.

3.1.3.10 Thickness of Capillary Fringe The capillary fringe is a zone of relatively saturated soil above the water table caused by upward draw of water into pore spaces by air-water surface tension and molecular attraction (forces of adhesion) between water and soil. The vertical thickness of the capillary fringe can range from centimeters (coarse grained soils) to over 3 m thick (fine grained soils). LNAPL typically perches on the upper portion of the capillary fringe. Even within the zone of greatest LNAPL saturation, some fraction of the pores may be occupied by water. The finer the soil texture, the greater the water content and the lower the LNAPL content will tend to be. Therefore, LNAPL thickness measurements from monitoring wells must be corrected so that the actual volume of LNAPL is not overestimated (Parker and Lenhard, 1990; Farr et al. 1990; USEPA/510/R-96/001).

3.1.3.11 Microbial Assays Microbial assays, such as BART™ test kits, are used to inexpensively determine if significant populations of microbes are present. Findings can be used to plan enhanced in-situ bioremediation and to estimate if biofouling may occur. Assay results, combined with review of chemical analyses, can provide a general indicator of favorable conditions for microbes and identify whether microbes are aerobic or anaerobic.

3.1.3.12 Organic Carbon Content Natural organic carbon content (mass of carbon per mass of soil) is used to estimate the amount of contaminant sorption into soils/aquifer material and is integral to estimating remedial times. The method for measurement of total organic carbon is ASTM D2974.

3.1.3.13 Ground Water Flow Direction/Velocity Ground water flow estimates are used to estimate when initial release(s) occurred, how far the plume(s) has traveled, and the direction that the plume(s) has traveled. This information is used to position interceptor wells, trenches and monitoring wells. Flow direction and velocity are calculated using measured hydraulic gradients, hydraulic conductivities and effective porosities (Freeze and Cherry, 1979). It is important to base flow estimates on several rounds of water level measurements collected during each season of the year so that mean/net directions and rates of flow can be estimated.

3.1.3.14 Ground Water Recharge Area Natural ground water recharge occurs when the amount of precipitation exceeds the amount of run off, evaporation or vegetation transpiration. The percentage of total precipitation which infiltrates to ground water varies widely depending on soil types, amount of soil compaction, vegetation coverage, amount of paving, slope of the ground surface and depth to the water table. The software program HELP (USEPA 600/R-04/168a, 1994) is commonly used to aid in estimation of average annual recharge. Average annual recharge is used in calculations to estimate contaminant leaching from soils and in ground water models to aid in prediction of sustainable ground water extraction rates.

Identification of preferential recharge areas is important because they may locally cause higher ground water production rates, increased leaching or unusual ground water flow patterns which impact well/trench placement. Some of the more common reasons for preferential recharge are as follows:

- leakage from ponds, lakes, sewers, sumps and process areas;
- lawn and crop irrigation systems;

- localized soils with higher than average hydraulic conductivities (e.g. construction fill);
- contaminated areas where there is a lack of vegetation; and
- areas with disturbed soil or surficial depressions with reduce evaporation or run off.

3.1.3.15 <u>Partitioning Coefficients</u> The soil/water partitioning coefficient (volume per mass) is the concentration of a compound sorbed to soil divided by the dissolved concentration of the compound in ground water within the soil pore space (and at equilibrium). This parameter is a measure of the mobility of a compound in ground water. Compounds with coefficients that are orders of magnitude larger than 1 are essentially immobile (Freeze and Cherry, 1979). Soil/water partitioning coefficients which are used to calculate total contaminant masses from water concentration data are used in models to predict remedial times and used to estimate which compounds will take the longest to extract.

3.1.3.16 <u>Site-Specific Geologic Conditions and Subsidence Potential</u> Subsidence is sometimes caused by systems which extract water from silty/clayey formations (which undergo subsequent consolidation), and which dewater formations containing cavernous voids such as limestone karst terrain. In addition, subsidence can occur in the vicinities of wells which are improperly screened and generate large quantities of formation material.

Subsidence can cause differential settling of foundation structures, rupture of subgrade piping, evolution of sinkholes and (in the case of karst terrain) catastrophic collapse. If investigations reveal the potential for these events to occur, design is usually expanded to include maximum allowable dewatering, minimum distances between extraction wells and structures, and periodic subsidence detection surveys.

Design of appropriate well placements, arrays, depths, screen lengths and intervals, method of ground water extraction and injection, etc. must consider site-specific geologic conditions. Analysis of these conditions is used to assess, design, and develop appropriate controls and engineering for the construction of facilities such as tanks, piping (surface and/or buried) control rooms office facilities, and other structures that may be subject to failure(s) due to tectonic faults, growth faults, and soil and bedrock geotechnical properties (expansiveness, karst structures, subsidence etc.).

3.1.4 <u>Ground Water Characterization</u> Ground water should be characterized as completely as possible to facilitate effective design for extraction, treatment and injection. The following sections describe ground water analysis that should be performed prior to well design.

3.1.4.1 Cation/Anion (Ground Water Chemistry) Purposes of testing for cations and anions include: to assess the potential for precipitation of solids; to assess the potential for corrosion; to assess to extent to which natural attenuation is occurring; to support the evaluation of in-situ, and ex-situ treatment processes; and to determine compliance with discharge criteria, and injection criteria. Dissolved iron and manganese are the most troublesome metals commonly encountered. The most frequently used analytical list for cation/anion is as follows:

CATION		
Ammonia (NH_4^{+1})	Copper (Cu^{+2})	Potassium (K^{+1})
Aluminum (Al^{+3})	Iron (Fe^{+2}, Fe^{+3})	Selenium (Se^{+4})
Barium (Ba^{+2})	Lead (Pb^{+2})	Silver (Ag^{+1})
Calcium (Ca^{+2})	Magnesium (Mg^{+2})	Sodium (Na^{+1})
Chromium (Cr^{+6}, CR^{+3})	Manganese (Mn^{+2})	Zinc (Zn^{+2})

ANION	
Bicarbonate (HCO_3^{-1})	Nitrate (NO_3^{-1})
Carbonate (CO_3^{-2})	Nitrite (NO_2^{-1})
Chloride (Cl^{-1})	Phosphate (ortho-PO_4^{-3})and total (PO_4^{-3})
Fluoride (F^{-1})	Sulfate (SO_4^{-2})

GENERAL PARAMETER (Used as checks for the above Parameters)		
pH	hardness	alkalinity

The principal cationic elements (the positively charges ions present in ground water) are calcium (Ca^{2+}), magnesium (Mg^{2+}) and sodium (Na^{1+}), while the principal anionic elements (the negatively charged ions present in ground water) are alkalinity, chloride (Cl^-) and sulfate (SO_4^{2-}). Alkalinity is the measure of the acid-neutralizing capability in water and is primarily a function of the carbonate (CO_3^{2-}), bicarbonate (HCO_3^-), and hydroxide (OH^-) content of the water. Other components such as borates, phosphates, silicates and other bases also contribute to alkalinity.

The anion and cation content of ground water can be determined using the analyses listed in Table 3-1. Table 3-2 presents information regarding the interpretation of ground water data. The results for the individual anions, when expressed as milliequivalents per liter (meq/L), are summed to produce an anion sum. The results of the individual cations (meq/L) can also be summed to produce a cation sum. These sums should theoretically equal each other in potable water. The ion balance serves as a quick check on the accuracy of the individual analyses. The ion balance, based on a percentage difference, is defined as follows:

$$\% \text{ Difference} = \frac{100\ (\Sigma \text{ cations} - \Sigma \text{ anions})}{(\Sigma \text{ cations} + \Sigma \text{ anions})}$$

As the anion concentration increases, the criteria for acceptance area as follows:

Anion Sum (meq/L)	Acceptable % Difference
0 - 3.0	±0.2 meq/L
3.0 - 10.0	±2%
10.0 - 80.0	±5 - 10%

<u>Reference</u>: Standard Methods for the Examination of Water and Wastewater, 20th Edition, Page 1-12.

Other anions, such as fluoride (F^-), nitrate (NO_3^-) and nitrate (NO_2^-), and other cations, such as iron (Fe^{2+}) and manganese (Mn^{2+}), may also contribute to the ion balance. If the cation/anion balance is not within the acceptance criteria above, analyses for these additional anions and cations should be performed.

TABLE 3-1

GENERAL ANALYTICAL METHODS FOR CATION-ANION BALANCE

ANALYSIS	METHOD[1]
Alkalinity	SM 2320B
Aluminum	SM 3500-Al
Ammonia	SM 4500-NH_3
Barium	SM 3500-Ba
Bicarbonate	SM 2320B
Calcium[a]	SM 3500-Ca
Carbonate	SM 2320B
Chloride	SM 4500-Cl^-
Chromium	SM 3500-Cr
Copper	SM 3500-Cu
Fluoride	SM 4500-F^-
Hardness	SM 2340C
Iron	SM 3500-Fe
Lead	SM 3500-Pb
Magnesium[a]	SM 3500-Mg
Manganese	SM 3500-Mn
Nitrate	SM 4500-NO_3^-
Nitrite	SM 4500-NO_2^-
pH	SM 4500-H^+
Phosphate	SM 4500-P
Potassium	SM 3500-K
Selenium	SM 3500-Se
Silver	SM 3500-Ag
Sodium	SM 3500-Na
Sulfate	SM 4500-SO_4^{2-}
Zinc	SM 3500-Zn

[a] - Calcium and magnesium can be measured as hardness using SM 2340C. The measurement of the individual ions is more accurate.

SM - Standard Methods for the Examination of Water and Wastewater, 20th Edition.

[1] It is the responsibility of the reader to identify the specific analytical methods to be used to collect the project required data.

TABLE 3-2

INTERPRETATION OF CHEMICAL WATER ANALYSES AND ANALYTICAL METHODS

ANALYSIS	INTERPRETATION	ANALYTICAL METHOD
Alkalinity	Indicates the presence of carbonates, bicarbonates, and hydroxides. Calcium and magnesium carbonates will cause chemical encrustation of wells.	SM 2320
Calcium[a]	Dissolves from soil and rock, especially limestone, dolomite and gypsum formations. Along with magnesium, calcium is the source of most of the hardness and scale formation properties of water.	SM 3500-Ca
Chloride	Dissolves from rock and soil. High concentrations increase the corrosiveness of water.	SM 4500-Cl^-
Iron	Dissolves from rock and soil. If aggressive water (pH below 7) is present, iron will dissolve from pipes and pumps. On exposure to air, iron in ground water oxidizes to a reddish-brown precipitate. Concentrations exceeding 0.3 mg/L can favor the growth of iron-reducing bacteria that can stimulate stainless steel corrosion. Elevated concentrations in groundwater are indicative of biofouling.	SM 3500-Fe
Magnesium[a]	Dissolves from soil and rock, especially limestone, dolomite and gypsum formations. Along with calcium, magnesium is the source of most of the hardness and scale formation properties of water.	SM 3500-Mg
Manganese	Dissolves from shale, sandstone or alluvial material. Elevated concentrations in pumped ground water are indicative of biofouling.	SM 3500-Mn
Nitrate	Source is decaying organic matter, sewage and fertilizers. Concentrations exceeding background may suggest pollution. Nitrate encourages the growth of algae and other organisms which may contribute to biofouling.	SM 4500-NO_3^-
Nitrite	Nitrite is an intermediate in the nitrogen cycle, both in the oxidation of ammonia to nitrate and in the reduction of nitrate. Excessive concentrations in groundwater are indicative of a nitrate or ammonia source.	SM 4500-NO_2^-
Sulfate	Dissolves from rock and soil containing gypsum, iron sulfides and other sulfur compounds. Commonly present in industrial wastes. Sulfate in combination with calcium can form scale. Concentrations exceeding background may indicate sulfur biofouling from the oxidation of sulfides. In anaerobic systems, sulfate reducing-bacteria will utilize molecular hydrogen and produce sulfide. Sulfides are a cause of electrochemical corrosion.	SM 4500-SO_4^{2-}

[a] – Calcium and magnesium can be measured as hardness using SM 2340C. The measurement of the individual ions is more accurate.
SM – Standard Methods for the Examination of Water and Wastewater, 20th Edition.

It should be noted that these analyses are typically performed on filtered samples (0.45 micron filter) so that dissolved geochemistry can be understood. Regulatory agencies, however, may require that these analyses be performed on unfiltered samples. In that event, both filtered and unfiltered samples should be obtained for analysis.

Alternate electron acceptors, some of which are cation or anion, are important parameters for the evaluation of natural attenuation of hydrocarbon contaminants in ground water. These include NO^{-2} and SO^{-4}(Wiedemeier et al. 1995; Wiedemeier et al. 1996).

3.1.4.2 Total Dissolved Solids (SM 2540C) Total dissolved solids (TDS) analyses are used (in combination with ion analyses) to determine water hardness; the potential for scaling in extraction, treatment and injection systems; the potential for incompatibility with in-situ and ex-situ amendments to the systems; and the dissolved organic content of the water (as Total Volatile Dissolved Solids).

3.1.4.3 Total Suspended Solids (SM 2540D) Total suspended solids (TSS) analyses are used to determine if suspended solids should be removed prior to treatment and/or injection to prevent equipment plugging or fouling, and to prevent injection well slot or formation plugging. TSS data collected in monitoring wells may not be indicative of TSS levels in production wells due to differences in filter pack design, screen design, and high entrance velocities in production wells.

3.1.4.4 Total Organic Carbon (SM 5310) Total organic carbon analyses determine the total organic content of water including compounds or materials not specifically analyzed. These analyses indicate the potential total burden of organics to be treated by any non-specific in-situ and/or ex-situ treatment system.

Dissolved organic carbon (DOC) is obtained from the analysis of filtrates of groundwater samples. Samples should be filtered in the field prior to acidification. Samples are filtered through a 0.45 μm filter, acidified to a pH less than 2, and then analyzed using the same techniques as a total organic carbon (TOC) sample.

3.1.4.5 pH (SM 4500H^+ or Field Method) pH analyses are used to assess the need to adjust the extracted/injected ground water pH for in-situ and/or ex-situ treatment systems, assess the need for corrosion protection and specific materials of construction, and assess the compatibility of the water with pH sensitive or reactive amendments. This parameter is usually measured in the field. Buffering capacity of ground water should be measured in order to allow for proper plant design.

3.1.4.6 Oxidation-Reduction Potential (ORP) (Field Method) The ORP is used to measure the oxidation state of ground water that results from the geochemistry of the ground water. The analysis is used to determine requirements for providing electron acceptors (e.g. oxygen, nitrate, etc.) and to estimate incompatibility reactions of amendments due to the ORP (e.g. metal sulfide precipitates). ORP is also used to select materials of construction and operational controls to prevent corrosion, control odors, and reduce potential safety hazards (e.g. hydrogen sulfide). This parameter is usually measured in the field.

3.1.4.7 Microbial Assay Microbial assays, such as BART™ Test Kits, are used to inexpensively determine if significant populations of microbes are present. Findings can be used to plan enhanced in-situ bioremediation and to estimate if biofouling may occur. Assay results, combined with review of chemical analyses, can provide a general indicator of favorable conditions for microbes and identify whether microbes are aerobic or anaerobic (USEPA 600/K-93/002, 1993).

3.1.4.8 Toxicity Tests Toxicity tests are indicators of ground water toxicity to microbes for treatment design. Tests such as Microtox 7 indicate the collective toxicity for microbes.

3.1.4.9 Conductivity (Field Method) Conductivity correlates with the general hardness, dissolved solids content, and specific cation/anion content. This parameter is typically measured in the field. Highly conductive environments may require the need for galvanic protection for steel wells or the use of PVC wells.

3.1.4.10 Dissolved Oxygen (Field Method) Dissolved oxygen (DO) is an indicator used to evaluate intrinsic bioremediation and the potential for enhancing in-situ bioremediation. DO indicates whether oxygen is available as an electron acceptor. Conditions are usually considered aerobic if the DO is greater than 2 mg/L, and anaerobic if the DO is less than 0.5 mg/L. DO measurements are used in conjunction with concentrations of ionic species to evaluate the potential for well encrustation. DO measurements should be made using an in-line system with a probe or in-situ to minimize influence of atmospheric oxygen.

3.1.4.11 Hardness as Calcium Carbonate SM 2340C) Hardness as calcium carbonate is used as a generalized assessment of the potential for scaling, treatment process and microbial toxicity, and associated hard water problems. Hard water conditions may lead to well encrustation and declining production rates.

3.1.5 LNAPL Characterization The presence and extent of LNAPL must be understood in order for it to be remediated as a continuing source to the dissolved contaminant plume. References provide guidance for LNAPL characterization are as follows: API

(American Petroleum Institute) Publ. 4474, 1988, API Publ. 1628, 1989, Cohen et al., 1992, USEPA 600/R-92/247, 1992, USEPA 540/S-95/500, 1995, USEPA 510/R-96/001, 1996, USEPA OSWER Directive 9283.1-06, 1992.

3.1.5.1 LNAPL Source Information on the source of LNAPL is used to estimate the time of release, LNAPL constituents, and phase separation potential.

3.1.5.2 LNAPL Density (or Specific Gravity) Density is used to differentiate the potential for a sinking phase (DNAPL) and a floating phase (LNAPL). In addition, density measurements are used to correct water levels measured from wells which contain LNAPL (Parker and Lennard, 1990).

3.1.5.3 LNAPL Viscosity Viscosity is used to estimate the ability to move the free phase through the soil matrix to the recovery point/trench/well and pump or otherwise recover the free phase to the surface (ASTM D445).

3.1.5.4 LNAPL Solubility LNAPL solubility measurements (mass per volume) are compared to ground water concentration data to estimate the vertical and lateral extent of LNAPL between wells which contain LNAPL and those which do not. In addition, solubility measurements can be used to estimate the total volume of original LNAPL spillage. Finally, solubilities of individual compounds (Montgomery and Welkom, 1990; Leinonen and Makay, 1973) are used to estimate the relative concentrations of constituents in the ground water contaminant plume from a mixed, multi-component NAPL.

3.1.5.5 LNAPL Water Interfacial Tension (Surface Tension) Surface tension is used to estimate the LNAPL affinity for the soils/rock interstices and to estimate the extent of LNAPL ganglia formation for a given soil porosity, grain size, organic carbon content, etc. It also is used to select the appropriate surfactant(s) and other physical/chemical agents for enhanced recovery of the LNAPL (Boyd and Farley, 1992; Demond and Roberts, 1991; Feenstra et al., 1991). A related measurement is capillary pressure saturation characteristic (see Paragraph 3.2.3.10).

3.1.5.6 Areal Extent of LNAPL Site characterization for design of LNAPL recovery systems must include measurement/estimation of the vertical/lateral extent of free flowing LNAPL and residual LNAPL droplets. The extent of residual LNAPL is controlled by the physical properties of LNAPL and soil, the rate of migration and seasonal water table fluctuations which smear LNAPL above and below the water table. Distinguishing between mobile and residual LNAPL influences performance expectations, well placement, pump specifications, pumping strategies and screened intervals.

Areal extent is estimated from LNAPL thickness measurements (corrected for capillary fringe effects) and comparison of detected concentrations to aqueous solubilities (Evans and Thompson, 1986; Parker and Lenhard, 1990; Mercer and Cohen, 1990). The calculations use the parameters discussed in previous sections.

A small percentage of LNAPL is also sorbed to soil organic carbon. While the total mass of this sorbed LNAPL is usually small, it is important because it results in a complete exhaustion of the soils ability to sorb and retard the migration of dissolved contaminants.

3.1.5.7 Rate of LNAPL Movement Estimates of LNAPL migration rates (length per time) prior to startup are used to calibrate models which estimate LNAPL recovery rates. Migration rate estimates are also used to determine if remedial systems should be installed on a fast-track basis. LNAPL which is found to spread quickly towards water supply wells may warrant fast-track installation of interim systems until full scale systems can be brought on line.

LNAPL migration rates can be empirically observed by documenting dissolved concentration and LNAPL thickness trends in monitoring wells. Alternately (where monitoring data is lacking), migration rates can be estimated by calculation/models which incorporate the parameters discussed in previous sections (Abdul, 1988; Faust et al., 1989; Kaluarachchi and Parker, 1990).

3.1.5.8 Apparent LNAPL Thickness Apparent LNAPL thickness measured in a well is used (after correcting for capillary fringe effects) to estimate the volume and mass of LNAPL and to guide the selection of pump systems. (USEPA 540/S-95/500, 1995 and USEPA 510/R-96/001, 1996). LNAPL volume estimates cannot be inferred directly from well LNAPL thickness data without consideration of soil and NAPL properties, and may lead to over design of the extraction system. This is because of LNAPL accumulation above the capillary fringe, water level depression in the well, fluctuations in fluid levels (which trap NAPL below the water table during high water periods and immobilize NAPL in the vadose zone during low water periods), and impacts of well filter pack grain size distributions. Taken together, these and other factors result in a finding that the actual thickness of NAPL in the formation cannot be calculated from well fluid level measurements alone.

3.1.5.9 Effects of Soil Properties on LNAPL Thickness At a site where LNAPL such as gasoline or diesel fuel is present, these are typically observed in wells screened across the water table and capillary fringe. All too often, however, LNAPL is viewed as occupying an oil-saturated "pancake" in the surrounding formation, the thickness of which is misconstrued as being linearly related to the thickness of the measurable LNAPL in the well. Although LNAPL reveals itself as a discrete oil lens floating on the water in a well, it does not occupy a distinct layer of constant S_o floating on the top of the capillary fringe in the surrounding soil. This can lead to inappropriate system design.

Procedures for estimating actual LNAPL thickness are detailed in Parker and Lenhard (1990) and Farr et al. (1990).

3.1.6 Regulatory Issues/Permits The regulatory issues and required permits should be identified at the onset of the design process. Regulatory requirements can and do affect system design and implementation. Proper coordination with the regulatory agencies will expedite the design and implementation of systems.

3.1.6.1 Lead Regulatory Agency In most instances, a Federal or state regulatory agency will be involved to consult upon, oversee or maybe approve investigative and remediation activities. Early, open, and continued coordination with the lead regulatory agency is important to the development of realistic, protective cleanup goals as well as establishing criteria for compliance/long term monitoring.

3.1.6.2 Other Government Agency Involvement Other agencies, such as Federal/state landowners, resource agencies (such as the U.S. Fish and Wildlife Service or state equivalent), and local government entities may have an interest in the cleanup goals. At appropriate phases of the project, these agencies should be informed of project activities and given the opportunity to comment on response plans.

3.1.6.3 Permits Federal, state, and local permits may in some cases be required for investigative activities and implementation of remedial actions. Air emissions, well construction, soil disturbance, and utility hook-ups are examples of activities or resulting impacts that could require permits (see Section 1.4.2). Additionally, permits may be required for treatment/disposal activities. The lead time required to submit documentation and obtain permits should be specified in a time line developed during the design phase.

Agency counsel should be consulted to establish requirements for specific agency projects.

3.1.7 Feasibility Study Objectives of the Feasibility Study are as follows:

- develop a list of applicable remedial alternatives;
- compare, choose and conceptually specify the most appropriate combination of extraction transport, treatment and injection (if applicable) techniques;

- collect supplemental data to support the detailed design phase; such as treatability studies and pumping tests
- refine remediation goals as appropriate using collected data; and
- evaluate all alternatives applying the CERCLA remedy selection criteria.

The following sections summarize the steps to achieve these objectives. Documents which provide detailed guidance are as follows: Committee on Ground Water Cleanup Alternatives, 1994, USEPA 600/2-90/011, 1990, USEPA 600/8-90/003, 1990, USEPA 600/2-90/027, 1990, Satkin and Bedient, 1988, USEPA 540/R-92/071a, 1992, USEPA 625/6-85/006, 1985, USEPA 430/9-78/009, 1978, Driscoll, USEPA OSWER Directive 9355.4-03, 1989, USEPA 540/G-87/004, 1987, Zheng et al., 1991.

3.1.7.1 Design Basis The design basis is a succinct set of assumptions which define the area to be remediated, compounds to be treated and cleanup criteria. The design basis should include clear objectives with regard to system performance (e.g., is the system designed to capture entire plume, remediate high concentration areas, or to meet other performance criteria?). It should be noted that the construction and startup phases include comparison of actual conditions to assumed conditions and a feedback loop to the design team to determine if design or operating modifications are warranted. The design basis should consider the operation of individual wells, as well as grouped wells over the life of the project and how their operation affects remediation objectives.

The following design issues should be considered:

1) Cleanup Goals Cleanup goals are determined by regulations, modeling, client requirements, exposure risk studies and limitations of current technologies. These goals are used as the basis for system design, schedules for completion, areal limits of cleanup and cost estimates.

2) Plume Size/Configuration Defining the nature and extent of ground water standard exceedances defines the required areal extent of hydraulic capture. This element is typically defined on maps and cross-sections depicting the area within which dissolved concentrations must be actively remediated and the area (if any) within which LNAPL must be removed.

3) Soil Contamination Areal Extent It may be important to define the extent of contaminated soils or landfilled materials that may act as continuing sources of releases to the ground water. This element is typically specified on a map depicting the areal extent of soils/waste which may leach contaminants to ground water above cleanup goals.

4) Contaminant Mass/Volume Contaminant mass/volume is used to estimate cleanup time, performance expectations and waste management requirements. This element is typically specified in a table listing estimated masses of each compound below the water table (dissolved and sorbed) and volumes/masses of LNAPL (free flowing, residual, and sorbed).

5) Concentrations of Contaminants at Extraction Locations Data from the RI and modeling/calculations from the FS are used to estimate the startup concentrations of each contaminant at each extraction point and determine the rate of ground water extraction necessary to capture the plume. These estimates are used to calculate concentrations in the combined effluent so that appropriate piping materials and required treatment efficiencies can be determined. This element is typically defined in a table of concentrations by location.

6) Water Injection/Discharge Determining the fixed disposition of the treated ground water is a critical factor to system design. Evaluate the compatibility of treated water with proposed injection or discharge methods.

7) Cleanup Duration Constraints Regulatory agencies, responsible parties or third parties typically require specification of the minimum and maximum expected times of system operation. These estimates are used to estimate total project costs, required equipment durability, infrastructure requirements, permit periods, and to track performance during the operating phase. This element is usually specified in a project time line. It should be noted that project duration estimates are approximate and almost always require adjustment after system startup.

3.1.7.2 Comparison and Choice of Remedial Alternatives The objective of this task is to choose the most cost-effective remedial alternative which is protective of human health and the environment, complies with ARARs and meets agency requirements. Comparison of remedial alternatives typically proceeds in accordance with the following step-wise process:

1) Estimation of the minimum required configuration of each alternative to attain cleanup goals. This step typically entails use of models.

2) Estimation of project life for each alternative. This step typically entails use of models.

3) Estimation of the contaminant masses which would be removed by the minimum configuration of each alternative (to determine treatment, disposal and permitting requirements).

4) Estimation of permitting requirements and costs.

5) Estimation of capital and O&M costs including:

- cost (present and future value) versus time plots (annual and cumulative);
- normalized ground water extraction costs:
- dollars/gallon of water (if applicable);
- normalized remediation costs: dollars/pound of mass removed; and
- uncertainty of estimates evaluation.

6) Comparison of technical performance and reliability. The following criteria are commonly evaluated:

Waste Management Criteria

- amount of water generated requiring treatment;
- generation of hazardous waste requiring off-site disposal;
- generation of vapor requiring treatment;

Technical Criteria

- mechanical reliability and ability to operate "hands-off";
- ability to use existing facility infrastructure and personnel;
- technological maturity and ease of implementation;
- flexibility for expansion, enhancements and adjustments;
- lateral distance of hydraulic capture (e.g. ability to capture off-site ground water);
- mass removal rates;

- ability to mobilize and remove LNAPL;

- resultant concentrations at receptors; compatibility of treated water with injection or discharge

Risk Criteria, Community Relations Criteria, and Agency Compliance Criteria

- time to come on-line and become effective;

- potential for spills;

- potential for human (e.g. worker and public) exposure to compounds handled/treated or brought to the surface;

- visual impact;

- number of components to be off-site;

- required space and potential hindrance of facility operations;

- compliance with applicable regulations; and

- air, water and waste permitting requirements, if any, and costs.

These comparisons result in preliminary choice and conceptual specification of a remedial alternative. However, bench scale or pilot testing is commonly required to confirm applicability and provide sufficient information for design.

3.1.7.3 Bench Scale and Pilot Testing This task is used to collect additional data required for engineering design. Typical work can include the following: pumping or injection tests; bench scale bio-feasibility testing to determine the appropriate ratios of nutrients/oxygen and to estimate degradation rates; bench scale treatability testing; and pilot LNAPL recovery. Do not bypass pump tests or treatability studies even in projects where design is obvious. Any money saved in not performing pilot tests/pump tests will be expended trouble-shooting an improperly designed system later in the project.

3.1.7.4 Performance Criteria (or Expectations) Cleanup goals provide the end point requirement for remedial performance. Performance criteria are the day to day operational goals which, if achieved, will result in attainment of cleanup goals. Performance criteria are developed by comparing the design basis to results of models and calculations developed during comparison of alternatives. It should be noted that the construction and start up phases include comparison of actual conditions to assumed conditions and a feedback loop to determine if performance criteria require modification. Many systems obtain unexpected well yields and the designer needs to account for this possibility in well design. Refer to USEPA 600/R-94-123, Methods for Monitoring of Pump and Treat Performance.

1) <u>Extent of Hydraulic Capture</u> The hydraulic capture zone is the lateral and vertical volume of an aquifer in which there is a net inward flow of ground water towards ground water extraction points. The converse of this is the zone of hydraulic influence provided by injection points. Required capture zones and zones of injection influence are typically specified on maps and cross-sections which depict areas within which water must flow towards the extraction system and areas within which the aquifer must receive injected water. If detailed modeling has been performed, the maps will specify capture zones for individual wells in addition to the total system (defining treatment cells within the aquifer). Adherence to these criteria is evaluated during the operating phase by hydrogeologists who contour water levels measured from monitoring and extraction wells (accounting for well efficiencies) and who estimate directions of ground water flow.

The required zone of LNAPL capture is also specified for sites with mobile LNAPL. In general, the required capture zone is specified on a map as the extent of mobile LNAPL. Adherence to this criterion is evaluated during the operational phase by hydrogeologists who contour free phase thicknesses in monitoring wells (corrected for capillary fringe effects) and compare changes to the underlying zone of ground water capture.

2) <u>Water Balance</u> Water balance is the tabular listing of required extraction /injection rates from/to each well. The total specified extraction rate is sometimes greater than or less than the specified total injection rate. In these instances the water balance also specifies the required rates of water to be supplied from an outside source or sent to an alternate disposal location (e.g. an NPDES or POTW outfall).

Water balance is typically estimated during the FS based on pilot testing and modeling. The actual flows to and from individual wells after start up are never exactly the same as estimates. Therefore, water balance criteria include acceptable flow rate ranges for each well and the total system. In addition, the water balance typically includes specification of the maximum flow capacity for which piping and treatment systems should be designed. These separate specifications are typically 30% to 100% higher than the maximum estimated flows to account for potential future system expansions.

Operational compliance with water balance specifications is not typically measured on a day by day basis (except as applies to specific permit requirements) because estimates used to generate the specifications are typically based on long term average trends. Therefore, it is most common for water balance review, interpretation and operational adjustment to be performed on a quarterly, tri-annual or semi-annual basis taking into account seasonality of flow rates.

In some instances, water balance audits result in specification of pumping/injection schedules which vary over time (e.g. pulsed pumpage). Another example is periodic conversion from extraction to injection to remove contaminants from hydraulic stagnation points between wells.

3) <u>Pore Volume Exchange Rate</u> The pore volume exchange rate (pore volumes per year) is the number of complete pore volumes of water removed from the hydraulic capture zone per year. Pore volume removal rate criteria (e.g. two pore volumes/year) are developed by reviewing FS transport models to determine the amount of annual flushing required to achieve cleanup within the specified project duration (Zheng et al., 1991).

Pore volume removal rates are calculated during the operational phase by summing extracted water volumes and dividing removed volumes by the volume of water in the capture zone (calculated during the FS). It should be noted that hydrogeological interpretation of ground water levels should also be used to verify that the extracted ground water originated in the desired hydraulic capture zone.

4) <u>Dissolved Mass Recovery Rates and Mass Balance</u> As discussed in other sections, remedial progress is indirectly tracked by monitoring ground water extraction rates and concentration trends over time. Mass recovery rate (mass/time) is a direct measure of remedial progress which accounts for both ground water extraction rates and concentration trends. Mass removal rates are calculated by multiplying ground water extraction rates by contaminant concentrations in the removed water (with unit conversions).

Mass removal rate performance criteria are set by calculating the total mass of dissolved and sorbed contaminants in the plume (above cleanup goals) and using transport models to calculate the required annual removal rates (high in early years and low in later years) to complete remediation in the specified project duration.

Evaluation of mass recovery rates is not performed on a day by day basis (unless required by air or water discharge permits). However, mass removal rate audits should be performed at least annually. The mass balance audit should include two specific calculations: summation of mass removed based on effluent data and estimation of mass change in the plume based on monitoring well data. These calculations can result in several findings as follows:

- If the mass removed from extraction wells is significantly less than the change in plume mass, it is possible that natural attenuation mechanisms are contributing to remediation;

- If the mass removed from extraction wells is approximately equal to the change in plume mass, the extraction system is likely performing in accordance with design; and

- If the mass removed from extraction wells is significantly greater than the change in plume mass, there may be an active source (e.g. leaching soils), previously unknown areas of NAPL, or greater than estimated plume extent. This finding usually results in the need for additional investigation.

It should be noted that estimating the dissolved and sorbed masses of compounds in a plume requires numerous assumptions regarding extent, partitioning coefficients and equilibrium state. Therefore, these estimates must include a detailed sensitivity analyses by a qualified hydrogeologist. In some cases it is found that the degree of uncertainty associated with mass estimates is too high to allow meaningful conclusions.

5) <u>LNAPL Recovery Rates</u> Predictive tools for estimation of LNAPL recovery rates are not as accurate as those which are used to predict ground-water recovery rates. Therefore, the total volume of recoverable LNAPL is estimated during the RI (see Section 1.3.1) and the cumulative volume of LNAPL recovered is tracked and extrapolated to forecast total amount which is anticipated to be recovered. Operational extrapolations rarely match original estimates of recoverable LNAPL. This finding is as likely due to incomplete understanding of LNAPL extent/mobility as it is likely to be due to inadequate system performance. Another factor that may affect LNAPL recovery is that the mobility of LNAPL decreases as mass is removed. Most systems do not recover more than 50% of the mass estimated to be in place.

6) <u>Concentration Trends</u> The ultimate performance criterion for any remedial effort is attainment of cleanup concentrations outside the point of compliance (either by active remediation or natural attenuation).

Concentration trends are typically tracked to determine progress towards this goal. When concentrations fall below cleanup goals, systems are shut down and confirmation monitoring is performed. However, concentrations frequently rise back above standards after system shutdown due to slow desorption of contaminants from aquifer materials or continued contributions from sources. Previously discussed mass balance audits are used to estimate the likelihood for this "rebound" to occur.

Performance criteria for concentration trends typically consist of statistical procedures used to determine if anomalous monitoring results are due to bad data, seasonal variations or long term trends. Reference USEPA 530/SW-89/026 (1989) provides detailed guidance for developing appropriate statistical protocols.

Most states recognize that ground water extraction causes concentrations to decline asymptomatically towards cleanup goals and that natural attenuation mechanisms may contribute equally to remedial progress during the later stages of a project. Therefore, some systems are shut down before cleanup goals have been achieved because it has been demonstrated that natural attenuation mechanisms will be sufficient to complete remediation. Reference Wiedemeir et al. (1995) and Wiedemeier et al. (1996) provides detailed procedures to evaluate natural attenuation.

7) <u>Amount of Drawdown</u> Pumpage causes dewatering of water table aquifers. Because this technology removes contaminants through water flushing, remediation halts in the dewatered portions of the aquifer (potentially causing an increase in contaminant concentrations when systems are turned off). Therefore, most performance criteria include specification of maximum allowable drawdown in and near extraction wells. Maximum allowable drawdown is developed by balancing the desire for higher extraction rates (and more drawdown) against the desire for less drawdown (lower extraction rates). Maximum allowable drawdowns typically range between 5% and 30% of the saturated thickness in the vicinity of the extraction wells depending on hydraulic conductivities, dissolved contaminant distributions and the desire to minimize smearing of LNAPL.

Another important aspect in evaluating drawdown is the effect, if any, that the treatment system operation has on any other production wells in the vicinity.

Ground water pump and treat systems are typically designed to maximize ground water production. This objective may conflict with local or state ground water use rules and regulations which are designed to minimize aquifer drawdown and prevent production rate declines in existing water supply well fields. Consequently, design may require ground water modeling to estimate the impact of remediation systems on the sustainable flow rates from nearby supply wells. Similarly, agencies may require estimation of the potential impact on stream base flow in areas where ground water discharge to surface water is a significant percentage of the total stream flow. This work may also require consumptive use permits and/or public hearings in areas with limited ground water or surface water resources.

It should be noted that the water level in an operating extraction well is lower than the water level in the adjacent aquifer due to head losses across the filter pack and well screen. This head loss can be accounted for using methods detailed in Helweg et al. (1983) and Todd (1980).

3.2 Design The RI/FS process results in the specification of cleanup goals and conceptual choice of remedial technologies. This section details the following design phase steps:

- design of extraction/injection units (Section 3.2.1);
- pump design/specification (Section 3.2.2);
- piping design (Section 3.2.3);
- treatment unit design (Section 3.2.4); and
- electrical/controls specification (Section 3.2.5).

Documents which provide guidance regarding remedial system design are as follows: API (American Petroleum Institute) Publ. 1628, 1989, Hampton and Heuvelhorst, 1990, Mercer and Cohen, 1990, Testa et al., 1992, USEPA 542/B-95/002, 1995, USEPA 570/9-75/001, 1977, U.S. Department of the Interior, Ground Water Manual, USACE EM 1110-1-502, 1994, Wisconsin Dept. of Natural Resources, PUBL-SW183-9, 1993.

3.2.1 Design of Extraction/Injection Units The basic components of an extraction well are:

- the borehole;
- the filter pack between the borehole and screen;
- the well screen;
- the well casing above screen (and often including a silt collection sump below screen);
- the bentonite seal above filter pack and below grout;
- grout in the annular space between the well casing and borehole; and
- surface and near surface manholes, concrete pads and protection devices;

- means of measuring water level.

Wells sometimes include additional components such as piping within the filter pack to facilitate treatment chemical feeds/water level measurement, multiple tiers of casing to prevent cross contamination during installation, and multiple screen intervals. The following references provide comprehensive guidance for well design and installation: Driscoll, 1986, Hampton and H.G. Heuvelhorst, 1990, Helweg et al., 1983, Smith, 1995, USEPA 570/9-75/001, 1977, ANSI/AWWA A-100-90, 1997, ANSI/ASAE EP400.1, 1989.

The following sections provide brief summaries of key well design elements.

3.2.1.1 Specification of Numbers and Locations of Wells and Trenches The numbers and locations of extraction wells and trenches are specified during the FS for cost estimating purposes. The actual physical locations of the wells are determined during design. (see Section 1.3.2).

3.2.1.2 Specification of Screen and Casing Depths Screen and casing depths are specified during the design phase. The specified depth of well screen/casing should give consideration to the following issues. If LNAPL is present, the top of screen is usually placed above the seasonal high LNAPL level to allow skimming of mobile LNAPL (without ground water pumpage, if desired). If LNAPL is not present, the depth and length of screen are controlled primarily by three issues:

- placement of screen across the interval of highest ground water contamination to maximize mass/recovery; or
- placement of screen across the interval of highest hydraulic conductivity to maximize pumping rates and extent of hydraulic capture; or
- placement of screen deep enough so that the pumping water level will not drop into the screened interval, potentially causing biofouling or geochemical encrustation.

It is common that these three criteria conflict with one another, requiring the designer to prioritize these criteria for each site. It is common practice in the water supply industry to install wells with multiple screened intervals in different formations to maximize flow rates. This practice should be used very cautiously in remediation systems because of the potential for cross-contamination of formations and geochemical interactions which can cause biological fouling and chemical encrustation. For detailed guidance on depths of casing and screened intervals refer to: Abdul, 1992, Helweg et al., 1983, USEPA 570/9-75/001, 1977, and Wisconsin Dept. of Natural Resources, PUBL-SW183-9, 1993.

3.2.1.3 Specification of Casing Materials, Diameter, Screen Type and Filter Pack The primary considerations when choosing casing and screen materials are entrance velocity of water into the well, chemical compatibility with ground water/contaminants, cost and durability to withstand years of removing and reinstalling pumps. Steel (stainless or otherwise) casing and screen is usually preferred for long term projects and for sites with high contaminant concentrations or LNAPL. However, it should be noted that some NAPLs and highly saline waters may corrode stainless steel. USEPA 570/9-75/001, 1997 provides guidance for choice of well materials.

The primary objective in selecting well diameter, screen slot size and filter pack gradation is to maximize well efficiency. High well efficiencies (preferably above 80%) provide higher flow rates, reduce chances of encrustation and reduce wear on equipment. High well efficiencies also reduce the potential for cascading in the filter pack, reducing turbulence and entrainment of oxygen. Key approaches to achieving this goal are as follows:

- larger diameter wells and boreholes (balanced against cost);
- use of filter pack composed of washed, rounded quartz grains;
- design of filter pack and slot size in accordance with procedures defined in USEPA 570/9-75/001 (1975);choice of screen types which maximize open area (e.g. wire wrapped screens instead of machine cut slots); and
- use of screens constructed with inwardly directed "V" shaped wire (USEPA 600/4-89/034, 1989);
- The well screen and filter pack should be designed to match formation sand.

As with any construction project, local availability should be considered during specification of well materials to minimize cost and to facilitate future maintenance and repair.

3.2.1.4 Specification of Drilling Procedures Drilling methods should be specified that are appropriate, efficient and maximize post-construction well efficiency. Common drilling techniques include hollow stem auger drilling, mud rotary drilling and air rotary/percussion drilling (for rock). Hollow stem auger drilling is commonly used during the RI/FS because it allows precise soil sample collection. However, this drilling method causes significant smearing of clays causing inefficient wells which are difficult to develop. Mud rotary drilling can be used to greater depths than hollow stem auger drilling with less formation damage. However, mud rotary drilling (and subsequent development to remove drilling fluids system) can generate significant volumes of mud and water which can be expensive to dispose of. In addition, drilling fluids should be carefully chosen to ensure that they do not promote biofouling (e.g. polymers which biodegrade). Consideration needs to be given to predevelopment of wells that are installed using mud rotary methods. Air rotary/percussion drilling is commonly the only practical choice for installation of wells into rock.

USEPA 625/R-93/003a, 1993, EM 1110-1-4000, USEPA 570/9-75/001, 1975, USEPA 600/4-89/034, 1989, USGS (1989) TWRI, Chapter FI, Book 2, USGS (1997) WRI Report 96-4233, U.S. Army FM5-484, and ASTM D6286, provide detailed guidance for choice of appropriate drilling procedures. Drilling method should also consider locally available drilling equipment the local drillers usually have equipment that is well suited for the conditions found in the project vicinity. This can affect the project cost as well even if the local drillers use less productive equipment, they may give a better price due to familiarity with the area (less perceived risk) and the obvious low mobilization costs.

3.2.1.5 Bentonite Seal A bentonite seal should be installed in the annular space at the top of the well filter pack. This seal is installed between the filter pack and the grout discussed in the following section. Recommended hydration times for the seal should be carefully observed. By not allowing sufficient time for the bentonite seal to hydrate and form a low permeability seal, grout material could infiltrate into the bentonite seal and possibly into the filter pack. It is recommended waiting a minimum of 3 to 4 hours for hydration of bentonite pellets, or tablets when cement grout is used above the bentonite seal. If bentonite chips are used, the minimum hydration time could be twice as long. Normally chips should only be used if it is necessary to install a seal in a deep water column. Because of their high moisture content and slow swelling tendencies, chips can be dropped through a water column more readily than a material with a low moisture content, such as pellets or tablets. Bentonite chips should not be placed in the vadose zone. A 1 m (3 ft) minimum bentonite pellet seal must be constructed to protect the screen and filter pack from downhole grout migration. When installing a bentonite seal in the vadose zone (the zone above the water table), water should be added to the bentonite for it to properly hydrate. The amount of water required is dependent on the formation. It is recommended that the bentonite seal be placed in 0.15 to 0.3 m (6 in to 1 ft) lifts, with each lift hydrated for a period of 30 minutes. This method will assure that the bentonite seal is well hydrated and accomplish its intended purpose. A 0.15 to 0.3 m (6 in. to 1 ft) layer of fine to medium sand (secondary filter pack) placed atop the bentonite seal may further enhance barrier resistance to downward grout migration.

Bentonite seals (especially those set in water) should typically be composed of commercially available pellets. Pellet seals should be 1 to 1.5 m (3 to 5 ft) thick as measured immediately after placement, without allowance for swelling. Granular bentonite may be an alternate if the seal is set in a dry condition.

The final depth of the top of the bentonite seal should be directly measured (by tape or rod) and recorded. Final depths should not be estimated, as, for example, based on volumetric measurements of placed bentonite.

3.2.1.6 Specification of Grout The annular space between the casing and the borehole wall must be filled with a grout to prevent short circuiting of water between formations and the surface. Site specific conditions should be carefully reviewed to determine the appropriate type of grout. This is particularly important for the following conditions:

- specific state regulations regarding types of grout which may be used;
- sites which include chemicals which could degrade bentonite;
- sites with geochemical conditions which could prevent setup of cement or cause exothermic reactions which could melt PVC casing;
- pressure injection wells; and
- sites with anticipated subsidence.

Grout is typically installed using the tremie method in which the grout is pumped through a side discharge pipe to the bottom of the interval to be grouted. The tremie pipe is usually raised slowly as grout is introduced. CEGS 02521 Water Wells and CEGS 02522 Ground Water Monitoring Wells provide detailed guidance regarding grout specification and installation.

1) **Cement**. Cement grout, when used in extraction/injection well construction or borehole/well decommissioning, should be composed of Type I Portland cement (ASTM C 150), bentonite (2-5% dry bentonite per 42.6 kg (94 lb) sack of dry cement) and a maximum of 23 to 26 L (6-7 gal) of approved noncontaminated-water per sack of cement. The addition of bentonite to the cement admixture will aid in reducing shrinkage and provide plasticity. The amount of water per sack of cement required for a pumpable mix will vary with the amount of bentonite used. The amount of water used should be kept to a minimum. When a sulfate resistant

grout is needed, Types II or V cement should be used instead of Type I. Neither additives nor borehole cuttings should be mixed with the grout. The use of air-entrained cement should be avoided to negate potential analytical interference in ground water samples by the entraining additives.

2) **Bentonite**. Bentonite grout is a specially designed product, which is different from a drilling fluid by its high solids content, absence of cement and its pumpability. A typical high solids bentonite grout will have a solids content between 20 and 30 percent by weight of water with a density of 9.4 pounds per gallon or greater, and remain pumpable. By contrast, a typical low solids bentonite, as used in a drilling fluid, contains a solids content between 3 and 6 percent by weight of water. The advantages of using bentonite grout include (Oliver 1997):

- Bentonite grouts, when hydrated, exert constant pressure against the walls of the annulus, leaving no room for contaminants to travel in the wall.

- Bentonite grouts are more flexible and do not shrink and crack when hydrated, creating a low permeability seal.

- Placement using bentonite grouts is much easier because more time is allowed for setting.

- Bentonite high solids grouts require less material handling than cement.

- Bentonite grouts are chemically inert, which protects personal safety, equipment, and water quality.

- Bentonite grouts have no heat of hydration making them compatible with polyvinyl chloride (PVC) casing.

- Wells constructed with bentonite grouts can be easily reconstructed if necessary.

- Cleanup of bentonite grouts is much easier than with cement grouts.

Situations where bentonite grout should not be used are when additional structural strength is needed or when excessive chlorides or other contaminants such as alcohols or ketones are present. Under artesian conditions the bentonite does not have the solids content found in a cement-bentonite grout and will not settle where a strong uplift is present. Where structural support is needed, bentonite grout does not set up and harden like a cement and will not supply the support a cement-bentonite grout will provide (Colangelo 1988).

3) **Equipment**. All grout materials should be combines in an aboveground rigid container or mixer and mechanically (not manually) blended onsite to produce a thick, lump-free mixture throughout the mixing vessel. The mixed grout should be recirculated through the grout pump prior to placement. Drill rods, rigid polyvinyl chloride (PVC) or metal pipes are suggested stock for tremie pipe. If hoses or flexible plastics must be used, they may have to be fitted with a length of steel pipe at the downhole end to keep the flexible material from curling and embedding itself into the borehole wall. This is especially true in cold weather when the coiled material resists straightening. Grout pipes should have **SIDE** discharge holes, **NOT** end discharge. The side discharge will help to maintain the integrity of the underlying material (especially the bentonite seal).

3.2.1.7 Specification of Well Headers Extraction wells in low traffic areas are commonly completed above grade for ease of maintenance and housed within a small building to limit unauthorized access and protect components from weather. In areas with high traffic or aesthetic concerns (e.g. off-site), wells are usually completed below grade with metal vaults set in concrete or concrete vaults. A common mistake is to use vaults intended for monitoring wells for extraction wells. Monitoring well vaults do not include sufficient room for valves, controls or access for maintenance work. Inaccessible equipment and poor space layout makes it impossible to service or sample wells. The vault must accommodate performance of O&M activities, as well as O&M equipment. In addition, the smaller well vaults may sit directly on well casing transferring traffic loads to the well casing and potentially causing damage. Under circumstances where extensive instrumentation, spill containment or control devices are not required, pitless adaptors and buried valves can be used to provide simple, easy to access well heads. These two objectives accomplished by predevelopment are to set the filter pack and to remove fines from the well while they are still suspended in the drilling fluids. Pumping and surging the entire length of the screen in the predevelopment phase will more efficiently develop the well and result in shorter overall development time. The traditional development that occurs 48 hours after well installation will take a much shorter time to reach parameter stabilization.

The well head or vault should be labeled with a permanent, durable, weatherproof, rust proof identification plate secured to the well casing at an easily visible location. The identification plate should show the following information:

- site name;
- well name;
- drilling contractor and driller certification;

- date well was completed;
- top of casing elevation (feet, mean sea level);
- total depth;
- casing depth (feet) and inside diameter (inches);
- screen interval (feet); and
- static water level and date measured;

The well vault or manhole should be a water tight design to protect from flooding. A concrete surface pad should be installed around each well at the same time as the outer protective casing is being installed. The size of the concrete surface pad is dependent on the casing size but should be at least 3 feet x 3 feet. Round concrete surface pads are also acceptable. The finished pad should be sloped so that drainage will flow away from the protective casing and off of the pad. Well vaults or manholes should be protected from traffic using protective steel bollards which surround the well site and which are painted a conspicuous color to aid in visibility. Well sites and vaults should be secured from unauthorized access or vandalism.

3.2.1.8 Specification of Well Development A newly completed well should not be developed for at least 48 hours after cement grout placement. This will allow sufficient time for the grout to "set" and cure before development procedures are initiated. The well should be developed as soon as practical after this time. Long delays allow any filter cake on the walls of the hole to consolidate. Wells are developed to remove formation smearing, remove drilling fluids, and to form an even gradation from aquifer materials into the filter pack (to minimize siltation). It is often useful to "pre-develop" a well after installation of filter pack but prior to installation of bentonite seals or grout. The objective of pre-development pumpage is to ensure that the filter pack is properly seated (e.g. all bridging has been removed) to minimize the potential for settling following grout installation.

There are numerous methods for well development including surge blocking, water jetting, pumpage, injection of chemicals to break down drilling fluids, use of packers to isolate developed intervals, bailing and air lifting. The elements common to all effective development programs are removal of many borehole volumes of water and movement of pumps and development tools repetitively along all portions of the screened interval. Caution should be taken when using high rate pumps or jet-ting tools during development because they can damage or destroy the well screen and filter pack.

It is not acceptable to assume that remedial pumpage will be sufficient to develop a well. Additional guidance on well development may be found in ASTM Standard Guide D 5521 for Development of Ground Water Monitoring Wells in Granular Aquifers. Although this ASTM guide covers the development of screened wells installed for the purpose of obtaining representative ground water information and water quality samples from granular aquifers, the methods described in the guide can also be applied to wells used for other purposes. Driscoll (1986) provides detailed discussion on well development.

3.2.1.9 Encrustation/Fouling Potential As detailed in Sections 2.1.1.2 and 2.1.3.2, mineral encrustation and biological fouling are major causes of well failure. Water quality chiefly determines the occurrence of encrustation and fouling.

Ground water normally moves slowly through aquifers, creating a quasi-chemical equilibrium between aquifer solids and dissolved ions. In some cases, the water may be nearly saturated with certain ions. In these instances, slight changes in the chemical or physical conditions can upset the equilibrium and cause precipitation of relatively insoluble materials. The chemical equilibrium is often upset by the drop in water pressure, causing mineral encrustation when the well is pumped. (Driscoll, 1986; Helweg et al., 1983; and Smith, 1995).

The causes of biological fouling are analogous to those for mineral encrustation. Ground water contains indigenous populations of microorganisms (aerobic or anaerobic). The sizes of these populations are naturally limited by factors such as nutrient concentrations, temperature and dissolved oxygen content. Many contaminants can be used by microorganisms and result in increased populations. Installation of extraction wells can further increase microbial populations through introduction of oxygen, pressure changes and temperature changes. Dramatic population increases cause a build up of biomass in well screens, filter packs and in the formation, reducing ground water extraction rates. Some microorganisms also generate a secondary mineral encrustation.

As indicated in Section 3.1.4.1, the RI/FS should include cation/anion and microbial plate count analyses to allow design of systems which minimize encrustation/fouling and to specify maintenance procedures which remove the build up which occurs. References Driscoll (1986) and Smith (1995) provide detailed guidance for interpretation of investigative data regarding this issue and for choice of strategies for preventative maintenance.

The key elements of well design which influence the buildup or removal of encrustation are as follows:

Well efficiency should be maximized. This parameter is a measure of the head loss which occurs when water enters a well (ratio of water level change in aquifer to water level change in the well). Well efficiencies of over 80% may be achieved under optimal conditions in high hydraulic conductivity aquifers. However, lower efficiencies are typical for wells in lower hydraulic conductivity (finer grained) aquifers which have less screen area. Wells with low efficiencies require more drawdown and higher entrance velocities to attain desired flow rates resulting high pressure drops, temperature changes and introduction of air into the filter pack. These effects increase the chances for fouling. Efficiency is maximized through minimization of formation damage during drilling, appropriate choice of filter pack, maximization of well screen open area, and careful choice of screen shape. Helweg (1983) provides guidance for maximizing well efficiency.

If used, drilling fluids should be carefully selected. Some drilling fluids are biodegradable polymers which break down after a few days. These polymers can cause biofouling before the well is developed that is difficult to remove (Driscoll, 1986). Phosphate compounds also should not be used.

Consider installation of chemical feed systems. If RI data indicate that encrustation may be a significant problem, it may be appropriate to install continuous chemical feed systems. These systems typically feed chemicals into a tube installed in the filter pack or preferably into small wells installed several meters from the extraction well (Driscoll, 1986 and Betz, 1992).

Choose pumps/controls which minimize cavitation, potential encrustation surface areas, heating, agitation or dramatic water level changes in the well. In addition, if investigations indicate that aerobic biomass fouling is likely, avoid air driven pumps or controllers which include bubblers or air release valves.

3.2.2 <u>Pump Design</u> Pump design must be carefully considered in the larger design of extraction systems. Improperly specified pumps may result in a lack of system performance and / or system upset. Therefore, pump design is critical to the success of system design.

3.2.2.1 <u>Pump Specification</u> Choosing the right pump for each application requires data on the type of liquids that will be pumped, the amount of both suspended and dissolved solids expected from the well, the well location and geometry, and sometimes the type of treatment system to be used to clean the contaminants from the water. For example, dual-phase liquids may be present in the wells, with the lighter phase being pumped first with one pump that will be expected to pump water later in the cleanup cycle. Alternatively, a mixture of liquids might be pumped together. The pump must be designed for the worst case conditions. For example, the pump must be capable of lifting the heavier or more viscous liquids at the design flow rate and pressure required to transport this liquid to the treatment system. Consider choosing a pump that will support the process requirements of the treatment unit. For example, a top suction pump could be used to skim floating liquids in the well and have less water to process. A submersible centrifugal pump will mix the water and other liquids. This flow stream would be more difficult to separate in a pretreatment separator, and will produce an emulsification more difficult to treat in a biological treatment system.

In some cases, it is important to select pumps that will prevent or minimize the formation of emulsions. In these instances, the selection of pump type may have a significant effect on treatment system effectiveness. Low turbulence pumps may offer advantages over the more common submersible pump under these conditions.

Air displacement pumps can transfer liquids with a minimum of mixing, but the air in the system can lead to precipitation of minerals or oxides, that may scale the transfer piping system. Piston lift pumps with above ground drivers can work well if there is enough room above ground for the equipment. When selecting pumps, consider the maintenance of the pumping system. The system design should facilitate easy pump and ancillary equipment removal for preventative maintenance. With more moving parts down in the well, there is more work to maintain the system. CEGS 11212 Pumps, Water, Vertical Turbine contains appropriate specifications for pumps with either submersible or top mounted motors.

3.2.2.2 <u>Liquid Specifications</u> Characterization of the liquids to be pumped is required in a good pump specification. The design basis should include an analysis of the ground water hardness used to factor downtime, operation time, cleanup performance, and chemical costs. The possibility of bio growth should be evaluated. If suspended solids are expected, provide the maximum size and volume of solids to be pumped. If dissolved solids are expected, again the types and amounts should be specified (see Section 3.1.4.2). Solids have a tendency to plume, scale, erode, or otherwise decrease the efficiency or performance of a pump. Information on the expected levels of solids in pumped liquids can be used to predict maintenance cycles for pumps, as well as other equipment in a well. Typically, the specific chemical analysis of the ground water, as discussed in Section 3.1.4, should also be provided to the pump manufacturers. This will establish a design basis for the selection of materials for construction of the pump and related equipment.

3.2.2.3 <u>Flow Rates</u> The flow rate for a specific pump should be based on the results of hydrogeological modeling as detailed in Section 3.2.1.2. Each well pump should be sized to take into account possible changes due to seasonal fluctuations in aquifer characteristics, aging of the system, scaling of piping and pumps and performance of the cleanup strategies. The design flow rate should be the flow rate that will lower the water level in an extraction well or mound water in an injection well to the specified levels established in the hydrogeologic modeling. However, all pumps should be designed with a 20% margin. When practical, a pumping test should be performed to determine the possible sensitivity of flow rates from multiple wells. The pump specified should be able to pump the design flow rate at maximum efficiency, as determined by reviewing pump performance curves. Pump selection design should take into consideration the need for variable flow.

3.2.2.4 <u>Required Head/Discharge Pressure</u> Calculations should be based on site elevations, ground water draw down water levels, system pipe, valves, tank configurations and the maximum expected flow rate. Flexibility can easily be added to a system by installing a pump discharge flow control valve such as a pinch or globe type valve. The pressure drop for this control valve should be calculated with the valve at 70% open. This will allow a better range for turning down the system to reach the design flow expected for the system, yet allow for a flow control range to be used as the system needs or requirement may demand. As systems age, pumps and piping can scale and decrease the flow of liquids due to the increased system resistance.

3.2.2.5 <u>Valves and Other Wellhead Requirements</u> There are three specific needs for valves in the system. One is to isolate sections of piping so that pumps or individual well systems can be isolated for repairs or cleaning or changes in system configuration and zones of influence which may enhance cleanup. Second, flow rate control should also be considered as noted above in Section 3.2.2.3 on set flow rates from specific wells. The project may require enhancements to facilitate cleanup of problem areas, to segregate areas, or exclude selected areas from cleanup. The third is to install check valves to prevent reverse of flow back into well. Some pumps have internal check valves for pump protection, a complex system of pumps and piping that require additional check valves to minimize the back pressure on the down hole pump discharge valves. Smaller valves should be included at wellheads for sampling or testing. Each wellhead should have a provisions for water level testing equipment. Each wellhead should have accessible ports for collecting non-aerated samples or inserting probes (e.g., water levels, dissolved oxygen, pH, etc.). Well caps can have access holes and fittings, or the cap can be removable without interference to the well pumping system. As with pumps and other well equipment, the materials of construction for all wellhead and/or wetted parts should be specified to be compatible with the water and related contaminants of the well.

3.2.2.6 Long-Term Service Considerations When evaluating pumps, consider steady-state versus cyclic operation. Avoid improper cycling of wells in tight formations, as this can cause excessive pump wear. Consider efficiency when evaluating and selecting pumps. Consider the tendency of a pump to scale under well water conditions. Materials compatible with the liquids to be pumped should be carefully specified. Chemical compatibility charts are available from pump manufacturers and should be used to specify pump materials of construction. Specify a pump that is easier to maintain. Planned obsolescence of parts and equipment, especially pumps must be taken into account. Replacement pump components should be available for inevitable shutdowns. Consider the cost of the pump in a long term maintenance life cycle analysis. Controllable, variable speed motors on pumps may provide additional flexibility.

3.2.2.7 Encrustation/Fouling Potential If RI/FS data indicate that mineral encrustation or biofouling may be a problem (Section 3.1), the design engineer should choose pumps/controls which minimize cavitation, heating, agitation or dramatic water level changes in the well. In addition, if investigations indicate that aerobic biomass fouling is likely, the designer should avoid air driven pumps or controllers which include bubblers or air release valves.

3.2.3 Piping Design Proper piping design and layout is an integral part of any successful system design. Since the piping will provide the fluid transport through all manufactured parts of the extraction / treatment and injection system, it is important that the design and layout of the piping optimize system processes.

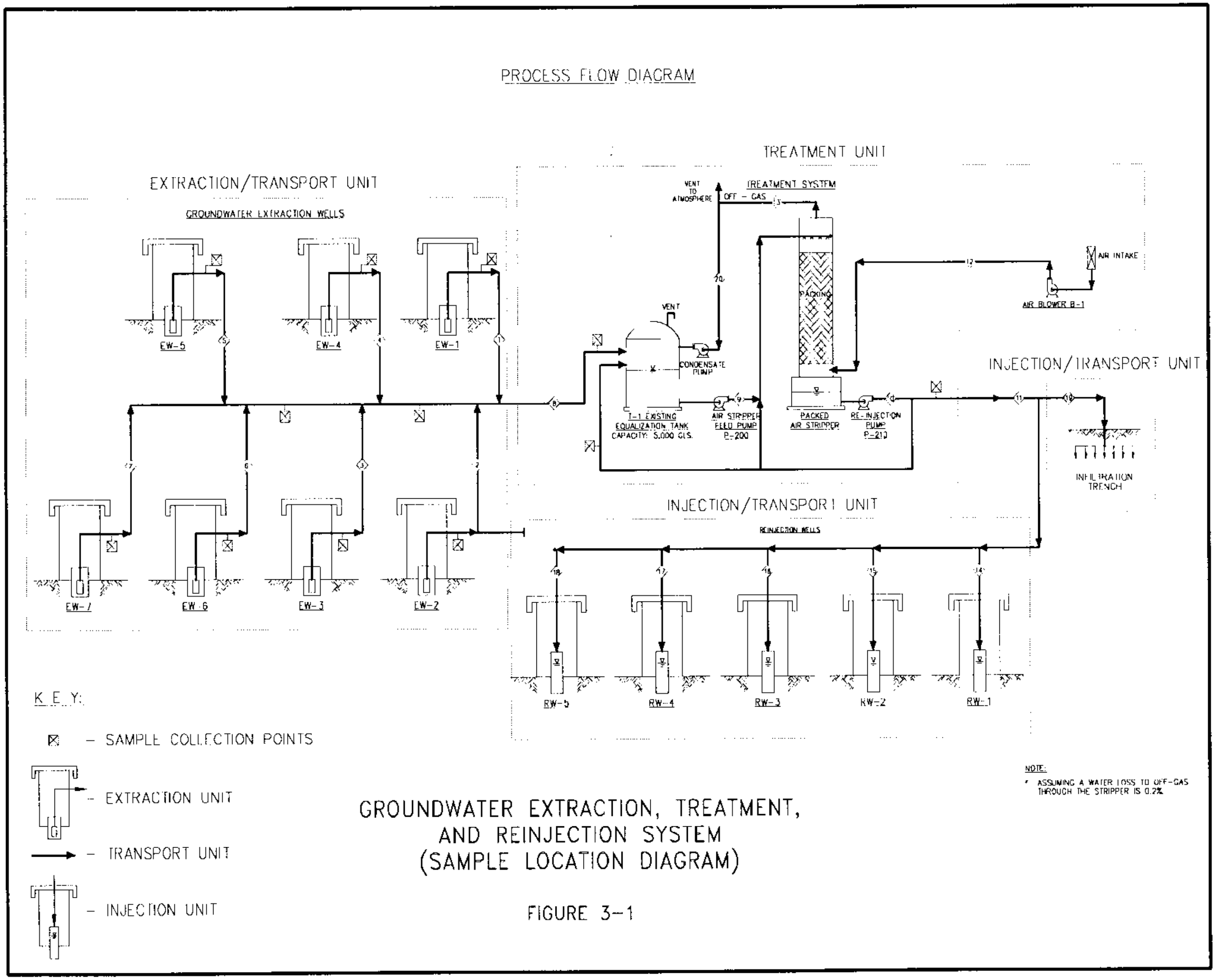
3.2.3.1 Piping System Layout Pipe layouts should be arranged to minimize pipe lengths and support maintenance requirements. The piping system should include clean-outs at each change of direction. Where RCRA compliance is required, double containment will be used on underground piping but may be eliminated, for example, if the above ground systems are inspected daily. Use welded joint piping in place of flanges to decrease the possibility of fugitive emissions and/or drips and drops that cause the same. Slope all lines so they can be drained to clean-outs when required. Avoid low and high point traps that can collect solids or air that can reduce flow though the system. Install high point vents and low point drains on all systems.

3.2.3.2 Flow Rate Indicators/Recorders Most systems require flow rate totalizers and instantaneous readings. Where practical, install flow meters to obtain good performance data from each well. Where totalizing is not needed, consider rotometers or similar direct reading instruments. This will then require individual flow lines from extraction wells or the area of extraction wells. Where multiple extraction wells are required it is advantageous to have flow meters that can support operations (i.e., well/pump performance over time). A flow meter or capability to measure flow should be installed at each well. Flow meters locations and layouts should be installed per the manufacturers instructions. Improper placement can result in false readings from meters due to improper flow through piping. Consideration should be given to maintenance of meter. In long term projects, such meters may have to be replaced several times. A properly placed and easily maintained flow meter will minimize system O&M costs.

3.2.3.3 Sampling Locations Sampling locations should be considered when the piping is designed. System should have access for sampling at the extraction, transport and injection units. Sampling points should be installed at each well head, at the junction of several laterals, and up stream and down stream of the treatment unit. Figure 3 depicts typical sample location points for a ground water treatment system.

3.2.3.4 Materials of Construction Materials should be chosen based on the most concentrated level of contamination from any one well. The life expectancy of the system should be considered when erosion and corrosion are possible. Some materials may soften and fail under startup conditions, but may be acceptable when levels of contamination drop. Also consider materials for structural parts of a system and avoid materials that will corrode or otherwise fail if exposed to the contaminants in the system.

3.2.3.5 Insulation/Heating Requirements Insulated lines are primarily for personnel protection and for heat or cold conservation. Insulate lines that may be stagnant during cold weather to avoid freeze damage. Also allow for draining of lines subject to freezing. Refer to CEGS 15080 Thermal Insulation for Mechanical Systems.



GROUNDWATER EXTRACTION, TREATMENT, AND REINJECTION SYSTEM (SAMPLE LOCATION DIAGRAM)

FIGURE 3-1

3.2.3.6 Encrustation/Fouling Potential Design pipe sizes that will not foul due to internal material buildup in a short period of time. The system should be designed to maintain fluid velocities that minimize sedimentation in points. Flow velocities should be between 2.5 and 8 ft/sec in all parts of the system. Those factors that cause a decrease in flow velocity, such as low spots or sags in lines can lead to sediment accumulation in the line which also increase the potential for plugging. Injection lines should avoid sharp 90 degree type turns before entering a well. Consideration should be given to broad curvature in injection system piping to minimize low velocity points. Do not over size lines. Install clean out fittings for line maintenance.

3.2.3.7 Manifold Locations Manifold piping to minimize pipe lengths. Design manifolds with settling velocities in mind. Slope manifold to support draining for cleaning.

3.2.3.8 Pipe Supports Pipe supports should be located according to the piping material specifications. Avoid long spans between supports to avoid sagging and resulting low and high points. Include supports that can resist water hammer and turning momentum. Allow flexibility in pipe supports to adjust for thermal expansion.

3.2.3.9 Buried/Surface/Overhead Locations Location of piping will be influenced by the applicable regulatory issues. Underground lines may need double containment and result in higher costs. Surface and overhead lines may require secondary containment if the lines are not inspected daily. It may not be advisable to route some lines carrying hazardous liquids overhead.

3.2.3.10 Valve Requirements Valve types (i.e., ball, globe, pinch, block) should be correctly chosen for their application (i.e., shutoff, modulating, block).

3.2.3.11 Flow Lines If velocities are low, solids will settle and plug lines. If lines are too small, lines may erode. Smaller lines cause high pressure losses and therefore require more power to move liquids or gases.

3.2.3.12 Head Losses Considered Equipment should be specified after all lines have been laid out. Pressure drop calculations should include losses for elevation changes, in-line valves and instruments. Accurate elevation profiles are required in this evaluation.

3.2.4 Treatment Unit Design Treatment unit design is not included in the scope of this DG. However, the following is a brief listing of key design considerations.

- Technology Options: Liquid flow and pressure from wells may be influenced by the treatment system used. Avoid high pressure requirements for well pumps. Where practical, install surge or equalization tanks before a treatment unit. The type of treatment system is influenced more by the contaminants being treated than by the extraction and injection units. However, the specifications for pumps and piping can be influenced by treatment choices.

- Influent Concentration Fluctuations: Influent concentrations in a treatment system are subject to constant variability due to inadequate characterization or inherent site variability. These fluctuations in concentrations may dictate operating conditions. Where possible install surge or equalization tanks before the treatment unit. Treatment systems designed to remediate highly contaminated water often cannot work efficiently with dilute concentrations.

- Effluent Concentration Criteria: Effluent concentration criteria: The effluent criteria for a system controls and dictates every aspect of treatment system design. A treatment system is only as effective as its ability to meet or exceed effluent concentration criteria. Specifications for extraction and injection equipment will be directly influenced by these criteria.

- Variations in well performance: Many systems obtain unexpected well yields and the designer needs to account for this possibility in the design of the treatment plant.

- Filtration Requirements: If the treatment system can not process solids, filtration will be required. It is preferable to treat solids in a process such as precipitation/coagulation and then filter solids. Good well development will set the filter pack and minimize the amount of suspended solids that will require filtration.

- Pilot Studies: Pilot studies should be performed for the intended treatment technology to ascertain its effectiveness. These studies could consist of bench scale studies, limited field trails and for vendor demonstration studies. Information gathered during this time can be critical to the successful implementation of the treatment technology.

- Treatment system objectives: Design of the treatment system should account for the likelihood that site hydrogeology and containment transport parameters will not support cleanup to MCLs or other proposed target levels. The system design should propose a method for the system to measure and document the attainment of an asymptotic (to approach an asymptote) value which is a limitation of the system.

- Rental vs. Purchase: In some instances, it may be cost effective to consider rental of the treatment system technology. An example of this is the rental of vapor extraction system equipment for a relatively short-term duration project vs. purchase of same equipment.

- Utility Requirements/Utility availability: The availability and requirements associated with local utility service should be considered as part of treatment system design and system operating costs. As an example: a ground water pump and treatment system may require access to a local POTW for discharge of treated water if no POTW or NPDES discharge point is available.

- Space Required/Available: The location and space requirements of a treatment system should be considered. Some treatment technologies such as oil stripping, may have significant space requirements, while others such as

- The aesthetics of treatment system design on the local environment should also be considered.

3.2.5 <u>Electrical/Control Specifications</u> Electrical control system design is outside the scope of this DG. However, the following is a brief listing of design considerations.

The control philosophy should be established early to influence the electrical and control specifications. Remote sites may require more monitoring and telecommunication. In these cases, consider relative costs of remote telemetry against costs for on-site or on-call personnel. Automated telemetry systems can be as simple as auto-dial units which notify operators when systems have shut down to transducer/control systems which allow operators to remotely review and control flows, pressures and water levels. Telemetry systems are most useful at the following types of sites:

- small (one or two well) systems which are mechanically reliable and require little or no oversight;

- large, complicated systems at inactive facilities with little available labor;

- systems which include outlying components off-site on property not controlled by the responsible party; and

- systems conveying high concentration contaminants under pressure.

- systems that have seasonal access considerations

Systems consisting of one operating plant with daily monitoring by an on-site operator can have less automation of controls. The overall philosophy of operation should be established in the FS and expanded at the beginning of the design phase. Shutdown and emergency alarms should be incorporated to avoid contamination leaks and spills. The following factors should be considered when developing a control philosophy:

- Equipment operation should be monitored to avoid shutdown due to improper maintenance. Vapor accumulation should be monitored as necessary for plant safety. These operating philosophies are the basis for the equipment controls and can influence choices of equipment.
- Safety Requirements
- Failure Modes for Valves
- Electrical/Fire Code Requirements (NFPA 70, The National Electrical Code)
- Electrical Phase Balancing
- Alarms/Process Trips
- Automation Needs
- Startup/Shutdown Sequences

3.3 Construction The construction phase of the project is critical to overall project success. The proper planning and implementation of construction can make the difference between an optimal system and one that requires excessive maintenance or reinstallation. The oversight of a qualified geologist is required for all phases of construction of the extraction/ injection well components. Refer to USACE EP 416-1-261 (1997) for the QA Representative's guide.

3.3.1 Preconstruction Review A preconstruction review is an evaluation of the specifications, materials and logistics required for construction of a system.

3.3.1.1 Specifications/Drawings Complete Specifications and drawings represent the designers' instructions for construction and a basis to compare variations and revisions. See USACE ER 1110-345-100 (1994) for design policy for military construction, and USACE ER 1110-345-700 (1997) for design analysis drawings and specifications, drawings, and construction specifications.

3.3.1.2 Constructability Review Constructability review is an opinion with regard to the ability to construct and operate the system as designed. Occasionally, the review may result in revised component sizing or location.

3.3.1.3 Spill Prevention Considered Certain contaminant/ground water mixtures are considered hazardous and thus may require spill protection such as double lined piping and retention systems around storage tanks, depending on the volume stored. Also, fuel storage and other petroleum products may require secondary containment.

3.3.1.4 Permits Obtained Permits may be required for certain construction and operation activities. Permits may be governed by State and local agencies.

3.3.1.5 Material Order Lead-Time Considered Material should be available prior to construction activities.

3.3.1.6 Equipment Decontamination Area Designated Typically, construction equipment requires decontamination prior to start work and prior to demobilization.

3.3.1.7 Safety and Health As part of the design phase, the designer must evaluate the ground water contaminant characterization data developed, and in consultation with appropriate safety and health professionals (the contractor's Certified Industrial Hygienist for contract designs, and the District's Qualified Industrial Hygiene Personnel meeting the Office of Personnel Management Standards for the Industrial Hygiene Series GS-690 for in-house designs) determine the applicability of all relevant Federal, state, and local safety and health worker protection regulations, most especially OSHA standards in general and 29 CFR 1926.65 in particular. Should the applicability of 29 CFR 1926.65 be determined based on the potential for relevant contamination exposures among workers during the construction phase, the designer, with the cooperation of the safety and health professionals, will comply with the requirements of ER 385-1-92 titled "Safety and Occupational Health Document Requirements for HTRW and OEW Activities, and draft a Health and Safety Design Analysis (HSDA) justifying as appropriate the safety and health requirements to be specified in the design specifications to the contractor. In drafting the design specifications, the designer will use CEGS 01351 "Safety, Health, and Emergency Response" in specifying to the contractor, the safety and health requirements justified in the HSDA. Note: the HTRW CX has taken the position that 29 CFR 1926.65, in and of itself, is not normally applicable during the O&M phase, with the possible exception of start-up activities, at typical pump and treat plants where the concentration of the ground water contaminants negates the reasonable possibility of O&M worker contaminant overexposures as defined by either OSHA or the

American Conference of Governmental Industrial Hygienists (ACGIH).

3.3.1.8 Silt Run-Off Control Measures Regulations may require minimization of silt runoff from construction sites. Control measures may include site grading and silt fences.

3.3.1.9 Water Source Approved for Construction It is important that water used for construction (i.e., water for mixing grout) is acceptable and does not contain substances that will react unfavorably. A chemical analysis of the water will determine if there is a potential for incompatible reactions.

3.3.1.10 Construction Waste Disposal Typically, construction will result in the production of potentially contaminated soil cuttings and ground water. Proper storage, transportation, and disposal are necessary.

3.3.1.11 Site Survey Completed A survey is advisable to properly locate and identify component locations.

3.3.1.12 Permanent Survey Benchmark Identified A permanent survey benchmark is necessary to reference component elevation and coordinates.

3.3.1.13 Critical Path Identified A critical path flow chart enables the construction oversight individual to easily identify the time-critical activities and assists in scheduling manpower and materials.

3.3.1.14 Other Scheduling Constraints Consider lead time for ordering material, equipment and labor.

3.3.1.15 Site Access Arrangements Authorization may be required from property owners or other individuals with an interest in the property.

3.3.1.16 Site Security Plan Complete A site security plan is required due to the potential of vandalism or theft of materials and equipment as well as to provide third-party safety. Proper site and well security are critical on HTRW sites.

3.3.1.17 Shift Schedules Set Systems requiring around-the-clock operation may also require 24-hour oversight.

3.3.1.18 Manpower Determined Consider the number and qualifications of individuals needed.

3.3.1.19 All Construction Techniques Specified Critical techniques such as filter pack or grout installation should be specified.

3.3.1.20 Utilities Cleared Buried and overhead utility lines must be located and cleared before construction.

3.3.2 Construction The construction phase of any extraction and treatment system project is critically important to the success of the project. Excellent system design will not mitigate inadequate construction practices. Therefore, proper oversight in the construction phase is required for system success.

3.3.2.1 Wells/Trenches

- **Construction techniques in compliance with plans/specs**: Construction must comply with the project documents for wells and trenches. Full time construction oversight should be provided by a qualified geologist or geotechnical personnel to assure strict adherence to specifications.

- **Trench supports used:** Good practice as well as OSHA regulations may require sidewall support for vertical trench construction In certain geologic formations. Trench support are may also be necessary as part of the construction if adjacent structures are present.

- **Well designation identified on wellhead**: For permanent monitoring wells, the well designation should be permanently identified on each wellhead for future reference during monitoring.

- **Well depth referenced to permanent benchmark:** Since the ground surface elevation can vary due to construction activities such as filling or grading, it is advisable to reference depth to a benchmark.

- **Materials in compliance with specifications:** Substitutions of materials called out in the drawings and specifications should be approved by the designers.

- **Wells located as shown on drawings:** Differences must be approved and documented.

- **Trenches located as shown on drawings:** Differences must be approved by the appropriate individual and documented on drawings and in writing.

- **Well casings installed as specified:** Casings must be installed at locations and to depths specified.

- **Casings designed to support wellhead equipment:** The structural capacity of the casing must be adequate for the extraction unit components.

- **Well screens installed as shown on drawings:** Material, well diameter, depth, length, and location are critical to proper operation. Differences must be approved by the authorized individual and documented on drawings and in writing.

- **Well Alignment**: After installation, verify that well alignment meets design specifications.

- **Gravel filters installed as specified:** Gravel filter construction significantly impacts well/trench performance. Filter pack should be uniform and free of fines. Filter pack may have to be field designed to match screen slot size to formation.

- **Well centralizers installed properly:** Well centralizers are required to keep the well casing in the center of the borehole during installation.

- **Bollards or other protection installed as specified:** Wellheads may require protection from traffic, mowers, etc.

- **Surface completion method according to specification:** Completion may include a concrete pad or manhole cover to maintain integrity of the well.

- **Infiltration Trench width/slope according to specifications:** Specifications and drawings are based on the designers calculation of trench volume. Differing volumes will cause performance variances. Differences must be approved by the authorized individual and documented on drawings and in writing.

- **Adequate well development, pumping tests:** May be required to determine if constructed well can meet design requirement.

- **Disinfection:** may be required.

- **Filter pack:** May need to be field designed to match screen slot size to formation. Filter pack should be free of fines.

3.3.2.2 Pumps

- **Pump Specifications:** Pump must meet the minimum contract design specifications as set forth in design drawings, and meet the designers specifications for materials and longevity. The electrical specification for all pumps must be recorded on the as-built drawings.

- **Pumps installed at specified depth:** Required for proper operation of system.

- **Foundations complete where needed:** Pumps and other equipment may require foundations.

- **Level control devices installed:** Level control devices are required for pump protection and for water level controls In tanks and wells. Level control devices will also be used as alarms to abnormal operations.

- **Injection pumps operational:** Pumps should be functioning properly after installation.

- **Storage tanks in place/not leaking:** All tanks and related fittings are to be inspected with tanks full of water and/or under operating pressure.

- **Dual-phase pumping in place:** Pumps should be properly placed (depth in well) and operational.

3.3.2.3 Piping Installation

- **Piping sloped according to specification:** Important to fluid flow, whether pumped or by gravity. Sloped lines will be easier to drain for maintenance/safety operations. Air release vents should be installed to minimize air traps.

- **Piping system maintenance:** Piping system should include cleanouts at each change in direction or low point crossovers.

- **Piping insulated as required:** Important to protect from freeze or corrosion.

- **Piping buried as required:** Burial depth is important to freeze/thaw protection and to protect the piping from vehicle traffic. Backfill procedures are important to proper loading of pipe.

- **Pipe supports per specification:** Location and spacing are important to proper pipe stress.

- **All pipe diameters and fittings as specified**. Important to maintain designed flows and pressures within specifications. Piping diameters and materials must meet specifications on project drawings.

- **Piping complete from wells to treatment system:** Hydrotest each section of pipe with clean water and check for leaks.

- **Piping complete from trenches to treatment system:** Hydrotest each section of piping with clean water and check for leaks.

- **Piping flushed/cleaned:** Pipes should be free of debris that could clog the pumps and be free of contaminants prior to startup.
- **Strainers/filters installed/cleaned:** Required for proper pump life.
- **Valves installed, operation verified:** One-way and manual valves must operate properly.
- **Pressure test complete:** Once all lines have been tested with clean water, drain the hydrotest water. Process water should not be introduced into the system until the hydrotest is completed.
- **Injection well piping:** May require terminations below static water level to minimize oxidation of water. Check valve may be required.
- **Sand traps:** May be required for some formations or poorly designed/developed wells.

3.3.2.4 Electrical and Instrumentation

- **Grounding installed/checked:** Each piece of equipment and all structures which require grounding should be tested for proper grounding to an underground grid or grounding rods.
- **Lighting/HVAC function**: Test all lighting circuits to see that lamps are operating properly. Set HVAC controls and monitor performance of the cooling and heating system for proper operation.
- **Lockouts/panels/covers in place:** Check all circuit breakers from the main disconnect through all branch circuits to insure that switches are set properly. Where tags and locks are required check for proper installation.
- **Disconnects in sight of unit being controlled:** Disconnect switches for each piece of equipment are to be in a line of sight with no obstructions.
- **Controls/alarms and interlocks functional:** Test each control loop and each alarm function to assure proper operation. Pre-operational testing should include these functions tests and a written report.
- **Power connected to monitoring devices:** All monitoring devices should be checked for proper wiring connections before power is connected to each instrument. There should be a power disconnect for each monitoring device ahead of

each device so power can be disconnected before work is done on an instrument.

- **Water Levels:** provisions should be made to measure water levels at each well

- **Flow rates:** should be monitored at each pump well to ensure accurate measurement of system performance.

3.3.2.5 Subsystems

- **Instruments calibrated:** Fluid volumes must be measured accurately to determine system performance relative to design. The gauges should be operating within the prescribed measurement range.

- **Water treatment system installed/functional:** Treated water must be cleaned by the treatment system to acceptable levels before discharge or injection.

- **Outfall/disposal systems functional:** Important to proper removal of treated water.

3.3.3 Post Construction Post construction activities and procedures can impact project implementation. These activities include important documentation of as built construction and the updating of system operation and maintenance plans.

3.3.3.1 As-Built Drawings Updated The as-built drawings document the actual dimensions and materials of the constructed system. The electrical specification for all pumps must be recorded on the as-built drawings.

3.3.3.2 As-Built Drawings Approved/Issued As-built drawings should be reviewed and approved by the engineer of record for the project.

3.3.3.3 Temporary Structures Removed To satisfy contractual conditions, all temporary facilities should be dismantled and removed from the site.

3.3.3.4 Operating Manual Ready as Reference Operating manuals should be written, reviewed and approved before systems are put into operation. The O&M should be updated after initial system shakedown to document system specific startup and shutdown procedures. The O&M should also include emergency and regular shutdown procedures. The O&M should specify what system performance data are collected, the frequency of data collection, how system performance data is to be managed, and the responsible parties for data management. The O&M must also set forth the design basis for system operation and include information such as how long the system can be allowed to be down without affecting system performance. If the system operator understands the design basis for the system, it is more likely that the system performance goals will be met.

3.3.3.5 Maintenance Manual Ready as Reference Maintenance manuals should be written, reviewed and approved before systems are put into operation. The maintenance manual should clearly state spare parts philosophy and inventory requirements. Planned outages to replace or maintain system components should be designed into system. The maintenance plan should specify the format for all maintenance records, how the records are to be managed, record prevention practices and dictate responsibility for who will review records. The maintenance plan should provide a schedule for system maintenance, including turnaround.

3.3.3.6 Decontamination Area Cleaned Wastes should removed and the site left clean.

3.3.3.7 Project Documentation/Records At the conclusion of construction activities, project records and documentation should be reviewed and updated to reflect system baseline prior to plant startup:

- Boring/Trench Logs Submitted
- Well Construction As-Built Drawings Submitted
- Well Development Records Submitted
- All Survey Locations Recorded/Submitted
- All Geotechnical Testing Submitted
- All Pumping Test Data Submitted
- All Analytical Sampling Results Submitted

3.4 Startup/Baseline Performance It is important to baseline the performance of any system as it is brought on-line to document its performance parameters. As the performance of the system varies over time, the delta in these measured system parameters will allow the system operators to monitor performance and to troubleshoot system problems.

3.4.1 Subsurface Components

3.4.1.1 No Piping Leaks Once the piping is installed, it should be inspected for leaks. Piping leaks in wells are not a problem from a contamination point of view but they do cause a loss in pumping performance and a waste of energy.

3.4.1.2 Drawdown within Specified Tolerances After the system has been operating long enough for drawdown to stabilize, water levels should be compared to performance criteria. If the operating level in each well is above or below the predicted level, a review by the project hydrogeologist should determine if the operating level is acceptable and if criteria or operations should be adjusted.

3.4.1.3 Monitoring Points Sample Composition within Expected Ranges Sampling from monitoring wells should begin as soon as the system has reached a steady-state condition. The sampling plan should be followed to begin the evaluations against the cleanup criteria.

3.4.1.4 Temperatures and Pressures within Expected Ranges Water temperature readings should be made as part of the sampling program. Water temperatures may influence the treatment system performance. The pressure at the well head can be used to check the operating performance of submerged pumps. Pressures and flow will change as the system reaches steady-state conditions. Adjustment may be needed to bring the operating conditions within expected ranges.

3.4.2 Pumps

3.4.2.1 Pumping test and Specific Capacity Measurement Each well should be tested for flow capacity to verify design assumptions and to set a baseline performance against which altered performance can be compared. Specific capacity should be measured by documenting steady drawdown for at least three discrete flow rates.

3.4.2.2 Flow Rates The operation of a pump can be checked by comparing the flow rate to the operating pressure. A reading of the flow and pressure can be compared to the operating predictions of the pump vendors' charts. The measured flow rate can also be compared to the design basis.

3.4.2.3 Start/Stop from All Control Mechanisms Check to see if all the pumps are pumping. Check to see that treatment system permissive signals are operating properly. Test operation of low water level cut off switch. Shutdown each well pump by removing the treatment system permissive signal. Try to pump the well down to the shutoff point. Pumps should not be allowed to run dry. Once a pump is shut down due to low water level in the well, check and record how long the pump is off before operation commences.

3.4.2.4 Current Draw/Voltage Match Specification for All Phases Each leg of power to a pump should be tested to see if the current draw is as expected. Current draw readings (amperes) should be taken after the system reaches a steady-state condition. Record and compare the readings to the predicted load expectations of vendor equipment.

3.4.2.5 <u>No Excessive Noise/Vibration/Temperature Rise</u> New pumps should not produce excessive noise or vibration. Either could be an indication of a pump problem or a pump that is operating off the pumps' design point. A noticeable rise in the water temperature can indicate that a pump is running hot.

3.4.2.6 <u>Dual-Phase Systems Are Compatible with Each Other</u> Pumps designed to remove water and lighter floating liquids need to be check for proper operating conditions. These pumps have a narrower operating range than most pumps for best removal of floating liquids.

3.4.3 <u>Systems</u>

3.4.3.1 <u>Startup/Shutdown Procedures Documented</u> Actual startup/shutdown procedures for systems may differ from design or O&M plans due to unforeseen circumstances. During initial system operation, these procedures are refined. These actual startup/shutdown system processes must be documented and incorporated into the site O&M manual.

3.4.3.2 <u>Control System Operates within Set Parameters</u> Each operating condition being monitored in the control system should be tested before operations begin. Where operating conditions and recording equipment allow, check to see if the actual conditions are within expected parameters. In many cases, the actual operating conditions may be different that predictions.

Record the differences and report them to the project hydrogeologist or project engineer. If individual control loops require tuning, time should be spent adjusting the controls to reach a steady-state condition. Check to see if controls are making slow swings in achieving required operating parameters. Report any dynamic control functions that do not appear to settle down.

3.4.3.3 <u>Instruments Hold Calibration</u> All instruments should be tested for proper performance. Calibrate all instruments or test each instruments accuracy against standards. Have instruments recalibrated after a short period of time to check for proper operation.

3.4.4 <u>Baseline Measurements</u>

Effective baseline measurements and continued performance monitoring requires measurements of all monitoring and pumping wells for flow rates, water levels, LNAPL/DNAPL levels, total well depth vacuum data, etc. It is important that these measurements are baselined at system startup and that they continue to be monitored through the life of the project to monitor system effectiveness.

3.4.4.1 Ground Water Elevation The water level in every injection, extraction of monitoring well must be measured before commencing system operation.

3.4.4.2 Flow Rate Baseline Record baseline flow rates for each well pump, the total flow to any treatment system, and the flow to the outfall or injection unit. The rate should be taken after the system reaches a steady-state condition. Adjustment may be required to improve the performance of the entire system.

3.4.4.3 Dissolved Contaminant Concentration Baseline Prior to system startup, record the dissolved contaminant concentration so that system performance can be monitored against a baseline. Baseline water levels in all wells should also be established before turning system on.

3.4.4.4 LNAPL Recovery Baseline Measuring equipment should be included to record the rate of recovery of NAPL. Record collection quantities regularly and review progress.

3.4.4.5 Water Recovery Baseline Water flow meters should be checked on a regular basis. Record flows at small intervals until flow rates are stable. Then wait longer between recording and average the flow rates to avoid misleading information from spot checking the flow rates.

3.4.4.6 Water Injection Baseline Once steady-state conditions have been reached, record and report injection flow rates. Compare to the expected rates. Also check the mounding of water in the subsurface to check against expected level. Report any discrepancies to the project hydrogeologist or project engineer.

3.4.4.7 Treatment Effectiveness Samples of water after treatment should be analyzed at short intervals at the beginning of operation. Once systems are running in a steady-state condition, tests should be performed as necessary to confirm that the systems are operating as expected or as required for permit compliance. The timing of these analyses is typically stipulated in system start-up plan or specified by regulation.

3.5 Operating Performance Operating performance is monitored to determine compliance with performance criteria specified during the FS (Section 3.2). This section summarizes specific measurements to aid in this in this evaluation. USEPA 600/R-94/123, 1994, provides detailed guidance on this topic. Evaluate site data during performance against system performance predictions derived from design models using a network of monitoring and extraction wells and update any model accordingly. The design verification of an extraction/irrigation system continues for months or years into system operation. The O&M contractor should know the system performance design so that they can monitor for variation in performance from design.

3.5.1 Chemical Characteristics

3.5.1.1 Concentrations at Wellheads/Trenches This information is used to establish baseline concentrations for the injection/extraction wells, to provide initial concentrations for any surface treatment system, to show areas/wells that are exceeding/meeting/below design/model predictions of concentrations at various stages of the remediation once the pumping system is activated. This information also can be used for determining/confirming the well locations as designed and the need for additional wells or extraction/injection volume to increase remediation.

3.5.1.2 Concentrations Entering Treatment System This information is used to establish a baseline concentration of ground water entering the treatment system.

3.5.1.3 Concentrations Leaving Treatment System This information is used to evaluate the performance of the treatment system to assure compliance with the effluent treatment requirements, particularly for injection or discharge. The information also is used to evaluate the operating conditions of the treatment system to modify the system or operations, if necessary, to optimize system performance. The data are used in monitoring compliance when the treated water is injected back into the aquifer. The effluent data are a useful tool for scheduling or rescheduling the maintenance program for the treatment system components.

3.5.1.4 Concentrations in Monitoring Points This is the most vital information during the remediation process which monitors the progress of the remediation system. This information provides a measure of the overall effectiveness of the remediation system. Data are collected at regular intervals and evaluated to determine if the pumping system is working efficiently or adjustment needs to be made. It is also used for reporting the effectiveness of the system.

3.5.1.5 Concentrations in Injection Water The concentrations of the injection water is useful for monitoring injection compliance and assuring a chemical balance between the injected water and the aquifer water.

3.5.2 Physical Characteristics

3.5.2.1 Ground Water Temperatures This information is useful for design and operation of surface treatment systems that require constituents/processes pre-heating (e.g. air stripping). The data also are used to assess the practicality of temperature-sensitive in-situ treatment processes such as bioremediation, air sparging, etc.

3.5.2.2 Wellhead Pressures Data on wellhead pressures are used to evaluate the operation of the pumping system. The information also provides an early warning, if a change in pressure signals the pump/piping may be failing to perform within design range.

3.5.2.3 Suspended Solids This information is used to monitor ground water extraction effectiveness and to determine if extraction activities are causing excessive drawdown of fines into well. Ground water discharged from extraction wells and added to injection wells should be analyzed for total suspended solids (TSS). This can be measured with a Rossum valve at the well head. Levels of TSS which exceed 500 mg/l may indicate that there may be excessive infiltration of fines into the extraction well.

3.5.2.4 Ambient Temperature Ambient temperature is used during operations of both in-situ and ex-situ treatment systems, to guide the design, construction and operations of various temperature protections for the piping/treatment system. Extreme temperatures also impact the performance of the pumps, instruments, valves, and similar components of the system. Temperature can also change aqueous solutions of compounds, changing the potential for scaling, and mass recovery of certain contaminants.

3.5.2.5 Water Flow Rates Flow rate is used to assess the system throughput conditions and is monitored to determine that rates meet design. Data may indicate an impact on design/permitted injection rates and discharge rates and guide adjustments to increase or decrease the extraction/injection rates. Flow rates may indicate short circuiting or impact from surface water bodies (lakes, leaking pipes, infiltration) if individual or area wells are very high or low contributors. Section 3.1.7.4 discusses interpretation of flow rate data.

3.5.2.6 Temperatures/Pressures in Treatment System Monitors the performance of the treatment system with variance from design indicates either design, construction, operations, corrosion, scaling, pipe plugging, or mechanical equipment problems.

Extreme cases of either high or low temperature and pressure may indicate significant treatment system design, operations, or maintenance and repair issues, leading to total system failure. These parameters should be monitored routinely as part of the systems O&M requirements to pinpoint root causes for non-design performance. In-situ system non-design pressure/temperature extremes can indicate a design or aquifer characterization problem(s), plugging of the aquifer, incompatibility with amendments, excessive well siltation, poor well construction (packing, purging, well breakage etc.) biofouling, corrosion, or scaling or pumps or well body.

3.5.2.7 Injection Water Temperature/Pressure Injection water temperature/pressure data monitors system operations compared to design/modeling predictions. Extremes of temperature/pressure can aggravate marginal incompatibility problems, causing formation of precipitate and reducing the injection rate. Excess temperature and pressure can rupture well casings and well heads, shorten the life of pumps, increase the rate of aquifer plugging, damage the formation, etc. and usually indicate a design or operations problem.

3.5.2.8 Ground Water Drawdown (Extraction Wells) Measurements of drawdown are used to determine compliance/ conformation with design. Excess drawdown may indicate poor characterization of the aquifer, operational problems (excess pump operation), low recharge and injection, etc. Excessive drawdown can also result from poor pump operations, poor well construction, incomplete well development, inadequate characterization of the aquifer and formation, unanticipated rapid recharge sources, inadequate well development, excess injection, etc. By monitoring and calibration, drawdown is used to optimize the remediation process. Drawdown is also used along with pumping rate to calculate specific capacity. This is one of the most important indicators of well performance and can be used as a predictor of problems. Section 3.1.7.4 discusses drawdown performance criteria.

3.5.2.9 Monitoring Point Drawdown/Mounding Excessive or inadequate monitoring point drawdown/mounding can indicate poor location of extraction/injection wells/trenches. It may also indicate impacts by other users of the aquifer, incomplete hydraulic characterization, or clogging of the formation. See USEPA 600/R-94/123 (1994), Methods for Monitoring Pump and Treat Performance.

3.5.2.10 Volume of Water Pumped Measurements of the volume of water pumped, when compared to pore volume exchange requirements are used to estimate the progress and duration of any ground water remediation program. The volume of water recovered is an overall indicator of the performance of the extraction, treatment and injection unit. This indicates if the design is appropriate and if remediation should meet schedule if all other factors are operating in the design range. Low volume recovery is a general indicator of problems and requires review of specific operational parameters to identify a specific cause or causes for the failure to meet design. Higher recovery than design volumes may indicate superior system performance but may also indicate the need to evaluate treatment capacity and performance to assure treatment. Section 3.1.7.4 discusses water balances and pore volume exchange performance criteria.

3.5.2.11 Volume of LNAPL Pumped Measurements of the volume of LNAPL recovered are compared to the estimated volume developed during the RI/FS. Data are used to track the removal of the estimated volume to determine progress and the potential end point for LNAPL treatment. Lower than design volumes of LNAPL can indicate a poor design, inadequate characterization, inadequate technology for LNAPL recovery, poor well construction, inadequate pump survey, etc. Section 3.1.7.4 discusses LNAPL recovery criteria.

3.5.2.12 Pump Amperages Pump amperages are measured to determine the "work" being done by the pumps to assess their efficiency at pumping water. Pump amperage "draw" is an indicator of the water pumped based on the "work" done by the pumps. Typically pumps will have an operating amperage range in which they are expected to operate based on the design. Pump operations outside this range may indicate poor performance by the pumps (i.e., seal leaks, mechanical wear, impeller damage, electrical short-circuiting, etc.) or inappropriate design (i.e., pump over/under sized; piping inappropriate, pumping head inappropriate for pump, etc.).

3.5.2.13 Subsidence Monitoring The O&M plan should include a schedule (typically once or twice per year) for periodic visual inspection at pre-determined benchmarks to determine if subsidence (due to consolidation of fine grain sediments which have been dewatered or collapse of voids) is occurring. Any noted anomalies should be reported immediately as set forth in the O&M plan (see Section 3.3.3.4).

3.5.3 Biological Characteristics

3.5.3.1 Dissolved Oxygen Concentrations Measurements of dissolved oxygen (DO) are used to determine if oxygen is available as an electron acceptor. DO monitoring is usually one component of monitoring programs for in-situ treatment processes, and for assessing natural attenuation. DO data can also be used to map the extent of a petroleum hydrocarbon plume. Historical DO data can be used to determine whether a petroleum hydrocarbon plume is shrinking or expanding. However, for some types of contaminants (e.g., chlorinated solvents) biodegradation typically occurs in areas where oxygen and nitrate are depleted. This distribution of oxygen concentrations vertically and horizontally in the aquifer and the changes with time indicates the effectiveness of the remedial alternative. For in-situ treatment processes, oxygen distribution data may also be used to determine whether oxygen (or electron donors) is being delivered to the desired locations, and to guide the operational strategy.

It should also be noted that there are some abiotic reactions that can result in consumption of oxygen (e.g., conversion of ferrous iron to ferric hydroxide).

3.5.3.2 Dissolved Carbon Dioxide Concentrations Measurements of dissolved carbon dioxide concentrations are collected from extracted ground water used to evaluate whether biodegradation (or some other processes) is generating carbon dioxide concentrations above background and/or injected water concentrations. Care must be taken to account for other sources such as pH changes which may increase carbonate solubilization from soils and rocks. Coupled with dissolved oxygen concentrations, the data provide an indication of in-situ biological activity. Concentrations also are indicators of the carbonate equilibrium in the ground water and the potential for scaling due to hardness, pH changes, temperature changes, etc.

3.5.3.3 Nutrient/Oxidizer Concentrations The concentrations and vertical and horizontal distribution of natural and/or injected nutrients/oxidizers determines if nutrients/oxidizers are reaching those in-situ areas as modeled or planned. These data guide changes in operations to meet design concentrations including additions of new injection and extraction wells, assess the system's performance against the plan or model, and indicate areas where excessive concentrations may be of concern. Consumption of nutrients as indicated by the analysis results and the concentration distributions can indicate areas where degradation is occurring, etc.

3.5.3.4 Water pH Measurements of pH indicate the effectiveness of any pH control (direct by injection of agents or; indirect by injected water adjusted as part of a surface treatment system) in producing the desired in-situ pH. Changes in pH generated in-situ with acidic trends indicate organic chemical degradation and thus biodegradation. Deliberate changes in pH can be used to assess the inherent buffering capacity of the aquifer system.

3.5.4 Maintenance

3.5.4.1 O&M Logs System O&M Logs should be kept for all system maintenance. The O&M Logs must provide a record of system maintenance such as equipment replacement, calibration or repair. The logs should also maintain a record of physical and/or operational changes to the system.

3.5.4.2 Replacement Parts Planned obsolescence of parts and equipment must be taken into account. Filters or other parts that have to be changed regularly must be in adequate supply. Some system components may have estimated life spans of several years, but this is significantly shorter for pumps and motors critical replacement parts should be available for the inevitable breakdowns. If there are other systems operating at the facility, the designer should consider whether any standardization of system components is possible to make O&M easier.

3.5.4.3 Lubricate All Rotating Equipment per Manufacturer's Instructions The project O&M program should identify the schedule for maintaining and lubricating all rotating equipment. The O&M program should specify the schedule, and the material to be used for maintenance and replacement, if required. The maintenance procedures should be followed and maintenance records should be kept in the project maintenance log book. Any deviation from the procedures should also should be logged.

3.5.4.4 Clean All Traps and Filters All traps and filters should be cleaned/changed as indicated by changes in pressure drops measured across the filters and per the O&M maintenance program. Changes in sand content in traps over time should be noted. Spare parts/filters should be maintained at site to minimize system disruption. Records should be retained for all maintenance activities. These filters should be disposed of in accordance with the procedures specified in the O&M manual.

3.5.4.5 Check Instrument Calibrations Instruments should be calibrated to be certain that recording/monitoring is accurate and precise to assure actual operation is in accordance with the design, remedial intent, control philosophy, and O&M manual. Calibration assures identification of damaged or otherwise inherently inaccurate instruments and their replacement in warranty. Instrument calibration records should be maintained for evaluating operational conditions and failures.

3.5.4.6 Replace System Pumps Well pumps and other rotary equipment will have finite service life that will manifest itself over the duration of the project. Pro-actively schedule pump or motor replacement on a regular basis to minimize system disruptions and maximize system uptime.

3.5.4.7 Check Control System Logic and Alarms Systematic procedures for checking control system logic and alarms prevents false alarms and alarm failures. Good design should include signaling malfunction of any critical components on an unattended pump/treatment/injection unit. Design may include interlock systems to prevent accidental releases, particularly of hazardous materials or wastes. Routine checks of the control systems and alarms assure operation as integral components of the remedial system and process. Records of maintenance performed on the control system and alarms, including failures, can enhance future evaluation(s) of the entire system and future designs.

3.5.4.8 Checks for Encrustation and Biofouling Water levels should be measured at least quarterly from each recovery well and combined with measured flow rates to calculate specific capacities (Section 2.1.1.2). These specific capacities should then be compared to baseline specific capacities measured during startup to determine if a greater amount of drawdown is required to achieve the same extraction rate. The O&M plan should dictate (if possible) the levels to which specific capacities should decrease before action is taken. The O&M plan should dictate what tests are taken to determine if there is biological fouling. Laboratory and field testing of well water samples is typically required to evaluate the potential for encrustation (e.g., anion/cation testing). A commonly available field test kit for measuring microbial activity is the BART™ test kit. If field tests indicate that the well is biofouled, diagnostic evaluation for potential encrustation/ fouling should be performed. Diagnostic work may include analysis of extraction well water samples for cation/anion or microbial plate counts. If the drop in specific capacity is significant, pump systems may be pulled from the well and inspected for evidence of encrustation/fouling. Alternately, a camera survey of the well may be performed. In wells with a high degree of biofouling, a down hole camera may be ineffective due to reduced visibility from suspended organic matter.

Potential encrustation/fouling should be addressed as soon as identified, even if the reduction of system performance is still within acceptable tolerances. This is because removal of encrustation/fouling after performance has fallen below acceptable levels is usually orders of magnitude more expensive and difficult than when addressed during early stages.

TABLE 3-3

Considerations for System Design

System Component/Feature	Problems to Avoid	Preventative Measures
Well Placement	Recovery well outside of plume	Proper plume/capture zone characterization - use appropriate groundwater flow models for well network design
	Poor access/inability to workover well	Design system for periodic maintenance
	Excessive recharge from surface water	Ensure that capture zones are sufficiently far from surface water bodies
Well Design	Inappropriate screened interval resulting in groundwater and/or NAPL extraction rates lower than planned	Characterize hydrogeology for system design - use slug tests performed in relevant screened interval as design basis.
	Misses heavily contaminated zone	Proper hydrogeologic characterization prior to design/installation - use soil data from continuous coring as design basis. Consider using nested extraction wells.
	Inappropriate well diameter	Select optimum size based upon hydrogeology/system design/pump size and other measuring devices
	Inadequate well development	Appropriate well development method (surge wells in addition to pumping)- consider multiple well development events in silty soils.
Horizontal Wells	Depth control/changes in aquifer depth	Establish stratigraphy across projected extraction well area
	Installation of filter pack	Often difficult. Ensure that horizontal well is most appropriate for situation.
	Well development	Properly develop well - often difficult for horizontal wells
Screen-General	Mineral encrustation in groundwater with high calcium (Ca^{+}), magnesium (Mg^{+2}), and carbonate (CO_3^{-2}). Precipitation occurs due to changes in geochemistry caused by high water velocities through the well screen.	Select the well screen material, slot size, and pumping rate to ensure that the linear groundwater velocity entering the well is less than 0.1 ft/sec.

TABLE 3-3, Continued

Considerations for System Design

System Component/Feature	Problems to Avoid	Preventative Measures
NOTE: Avoid use of PVC in pressure injection wells, extraction wells in low transmissivity formations (wire wrapped steel screens provide a higher hydraulic efficiency) and at sites with incompatible contaminants.	Biological fouling. Occurs primarily in ground water with high dissolved iron and/or manganese (e.g., greater than 5 ppm).	This is a difficult problem to avoid. Accurately measure iron and manganese before designing the well field. Select largest appropriate screen slot size. Select pumping rate that does not entrain air in the extracted groundwater (i.e., ensure that the water level in the well does not drop below the well screen). Avoid placement of wells in areas of high organic loading such as near septic leach fields. Consider installing air sparging wells around extraction well to precipitate iron and manganese *in situ* (i.e., the Vyredox process). Consider designing the well(s) with an automated cleaning system (e.g., acid rinsing).
	Physical erosion of screen/slots. High groundwater entrance velocities can cause groundwater with high mineral concentrations to react with steel well screens. PVC can be dissolved by a variety of NAPLs.	As with mineral encrustation, select the steel well screen slot size and groundwater pumping rate to ensure that the linear groundwater velocity entering the well is less than 0.1 ft/sec. Do not use PVC where incompatible NAPLs may be present.
	Siltation. Can occur in any well, but is most prevalent in wells that use inappropriate sand packs and/or are not developed well.	Proper design/selection of screen and filter pack (i.e., do not just rely on the well drillers' judgement); proper well development is critical; provide a minimum 1-foot sump at bottom of well to collect silt.
Pumps-Electric Submersible	Loss of pump down hole	Use a separate support cable to hang pumps. Do not use discharge line for support.
	Cavitation	Match pump selection to the anticipated recharge rate of the well (i.e., do not use an oversized pump); place pump low enough in the water column to maintain sufficient recharge rate; use in-well level sensors to control pump.

TABLE 3-3, Continued

Considerations for System Design

System Component/Feature	Problems to Avoid	Preventative Measures
Pumps-Electric Submersible (continued)	Electric motor failure -- often occurs due to overheating when pumping capacity exceeds water flow rate (recharge) into well.	Match pump selection to the anticipated recharge rate of the well (i.e., do not use an oversized pump); select pumping rate to minimize on/off cycling frequency; consider pneumatic pumps for average pumping rates less than 5 gpm. Do not use electric pumps if average pumping rate is below or near low flow rating of pump. For pump installations that make pulling the pump from the well difficult, use 3-wire pumps instead of 2-wire pumps. 3-wire pumps have separate, surface mounted control boxes that contain the pump start and run capacitors that can be serviced easily.
	Run-dry failures and excessive cycling	Match pump selection to the anticipated recharge rate of the well (i.e., do not use an oversized pump). Keep well screen free of obstruction (e.g., fouling). Use conductivity probes (inherently safe) for level control unless there is high (>5 ppm) dissolved iron in the groundwater which can precipitate and foul the sensor. Sleeve the conductivity sensor to prevent it from contacting the side of the well. Place the pump below the sensor ground in the well when using conductivity probes for level control, thereby acting as a failsafe by causing the pump to shut off before the well is "dry".
Pumps-pneumatic surface mounted for groundwater (e.g., double diaphragm pumps)	Freezing in cold weather; also can freeze if expanding air vents near liquid tubing	Heat or select more up-to-date design or use submersible (more expensive) pumps.
	Diaphragm or seal failure	Ensure material compatibility with contaminants, particularly if NAPL may be present.

TABLE 3-3, Continued

Considerations for System Design

System Component/Feature	Problems to Avoid	Preventative Measures
Pumps-pneumatic submersible for groundwater	Emulsion of discharge	Pump selection criteria should include a preference for low turbulence pumps.
	Air entrainment of water	Proper selection of pneumatic pumping system if entrained air is from compressor, i.e., more modern designs prevent mixing of compressed air and groundwater)
	Dirty air clogging valves	Proper design of air delivery system -- use oil-less compressor or filter compressed air.
	Encrustation of internal controller	Proper pump selection. As with well screen encrustation, ensure that pumping results in flow rates less than 0.1 ft/sec in high CO_3 ground water to avoid mineral precipitation.
	Fouled poppet valves due to siltation in the pump chamber	Use a well intake screen to filter silt entrained in the groundwater and slow build-up of silt in the pump chamber. Regular maintenance of the pump in high silt ground water. Regular/thorough re-development of the extraction well.
Pumps-hydrocarbon	Venting of air into well	Run air discharge lines to outside vent
	Pumps too much water	Raise pump inlet into NAPL layer
	Low hydrocarbon recovery rates	Consider vacuum enhancement
Piping	Water line freezing	Avoid low spots/traps; slope pipes toward extraction wells to drain during pump off-cycles; heat trace and insulate; low point drains
	Material incompatibility with contaminants	Proper selection of materials; flexible hose may be chemically compatible and light so that it is easily managed in the field.
	Encrustation/fouling	As with well screen encrustation, ensure that pumping results in flow rates less than 0.1 ft/sec in high CO_3 ground water to avoid mineral precipitation. Provide access points to clear/clean lines.
	Pipe Failure	Select appropriate bedding material and cover thickness; proper size and location of pipe hangars and supports
	Siltation	Proper pipe sizing; maintain proper and continuous pitch and avoid low spots/traps

TABLE 3-3, Continued

Considerations for System Design

System Component/Feature	Problems to Avoid	Preventative Measures
Compressed Air Systems	Overheating	Proper compressor sizing; maintain cooling capacity, air circulation and room ventilation; minimize on/off cycling
	Water Condensation	Design proper water removal equipment (i.e., air dryer, desiccants, and collection or surge tanks
	Excessive cycling of compressor	Allow for sufficient air tank capacity in design
Air Lines/Meters	Contaminated with construction dirt	Clear before final assembly
	Excessive moisture in air leading to rusting pipes and freezing of pipelines	Plastic or stainless pipes and air dryer installation
Transfer Storage Tanks	Sediment build up	Effective well design and well development; include appropriate settling or filtration component and access parts for cleaning out sediment
	Corrosion	Proper material selection
	Overflowing	Selection and coordination of appropriate level and flow controls; evaluate/balance system flows
	Foaming in tank	Design to minimize water aeration (e.g., locate inlet below free liquid surface)
Instrumentation	Level control fouling/encrustation	Specify routine preventative maintenance or non-contact sensors such as proximity or ultrasonic
	Inaccurate level controls	Equipment selection; proper selection of measurement locations, consider pump size and placement with respect to well screen
	Foaming interfering with sensors or detectors	Evaluate foaming potential prior to design and incorporate measures to limit foaming such as sleeved sensors; use non-contact sensors such as proximity or ultrasonic
	Flow totalizer fouling or encrusted	As with well screen encrustation, ensure that pumping results in flow rates less than 0.1 ft/sec in high CO_3 ground water to avoid mineral precipitation. Select appropriate meters; install in areas to that are easily accessed for preventative maintenance

TABLE 3-3, Continued

Considerations for System Design

System Component/Feature	Problems to Avoid	Preventative Measures
Injection Wells	Fouling/Encrustation	Use drop pipe to reduce aeration of water. Add treatment chemicals to retard the formation of precipitates; design wells/trenches to allow cleaning and maintenance
	Flooding due to inadequate infiltration capacity	Include additional capacity (factor of safety) to account for unavoidable reduction in infiltration rate due to clogging from sedimentation or precipitation. Use slug tests performed in relevant screened interval as design basis.